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Identification and Analysis of Practices that Positively Impact Construction Productivity

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Identification and Analysis of Practices that Positively Impact Construction Productivity

by

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Thesis

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Engineering

The University of Texas at Austin

December 2010

Dedication

This thesis is dedicated to my beloved family for their love, continued encouragement and support.

To David Tortel, who provides me with support and encouragement.

Acknowledgements

I would like to thank Dr. Carlos H. Caldas for all his wisdom, guidance, availability, confidence and willingness to assist me and without which this thesis would not have been possible and to have offered me the opportunity to work on this interesting area of research. I am extremely grateful to him. I would like to thank Dr Fernanda Leite for her encouragement.

I am also thankful to the Construction Institute Industry (CII) for its financial support for both the project that constitutes my thesis and my education. This research was conducted under the guidance of CII Research Team 252. Their involvement and interest for this new index was a great source of encouragement. I would like to thank Dr Carl Haas and Dr Paul Goodrum for their continuous advice, suggestions and inspiration on many different problems so critical to the success of the project.

Special thanks to Gwennael Beirnaert, Erwan Chabert, Claire Davis, Mathieu Leduc, and Philippe Marouby, the French students from Ecole Centrale de Lille, for your continued support, your friendship and 16 great months in Austin, TX.

My family has been an endless source of love and support. I am deeply grateful to my parents, my sister, and my brother for their unconditional love and confidence in me and for installing in me the desire to learn and to be ambitious and driving me to succeed.

Very special thanks to David Tortel for his patience, love and advice throughout both my undergraduate and graduate programs.

Finally, special thanks to Sarah Meeks, Fernando Mondragon and Daniel Vargas, Construction Engineering and Project Management students, who provided me with so much advice, friendship, and supportive cynicism and who really made graduate school a much more rewarding exciting and international experience.

Abstract

Identification and Analysis of Practices that Positively Impact Construction Productivity

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Improvements on construction productivity benefits projects. These benefits are diverse and varied. Costs can be reduced, schedule performance can be improved, skilled labor shortage can be mitigated, and much more. These last few years, construction sites have undeniably made significant progress through advances in heavy equipment, tools, and materials. But there are still some areas that have strong potential to improve construction productivity such as craft information systems, materials management, and construction methods, which abound of opportunities that just need to be pursued. Innovations represent some of these opportunities, however if established process and practices for managing construction productivity are not effectively utilized and implemented, they are likely to have a little impact on construction productivity. This thesis summarizes a research study which aimed to identify productivity practices that have the most significant positive impact on craft productivity and to document and incorporate them into an implementation resource. Surveys involving over a hundred experts and extensive literature review were used to gather accurate data. Construction industry and civil engineering academic experts were also consulted to accomplish this goal.

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Chapter 1 – Introduction

PROBLEM STATEMENT

Construction productivity is a broad topic and has many different definitions according to its context. In this research it corresponds to labor productivity. It is defined as the ratio between work hours and units of installed work. This ratio is used to manage the craft productivity on a construction project, and the lower the number the better, i.e. the fewer work hours we use to install a given quantity of work the better for the project.

The improvement of construction productivity benefits the project. These benefits are diverse and varied. Costs can be reduced, schedule performance can be improved, skilled labor shortage can be mitigated, and much more. These last few years, construction sites have undeniably made significant progress through advances in heavy equipment, tools, and materials. But there are still some areas that have strong potential to improve construction productivity such as craft information systems, materials management, and construction methods, which abound of opportunities that just need to be pursued. Innovations represent some of these opportunities, however if established process and practices for managing construction productivity are not effectively utilized and implemented, they are likely to have a little impact on construction productivity.

MOTIVATION AND PURPOSE

Construction productivity has received a lot of attention over the last several decades. Some studies claimed that the construction productivity has not increased over the past 15 years (Bosthworth and Tiplett, 2003). However, some other researchers have reached contradictory conclusions. Indeed, the Center for Construction Industry Studies conducted different research studies on the relationship between equipment technology and construction productivity 10 years ago. These studies identified productivity improvements and concluded that reasons for these improvements were diverse. The most significant improvements occurred in machinery-intensive activities, such as site work. More recently, a study was conducted on the strength and types of relationships between advances on material technology and construction productivity. They found out that a strong and quantifiable positive relationship existed between improvements in material technology and improvements in construction productivity (Goodrum et al 2008).

Despite all those contradictory data, some opportunities for improving construction productivity still exist, and the primary purpose of the CII Research Team 252 (RT 252) Craft Productivity Research Program is to understand these opportunities to develop and validate a roadmap of the practices that significantly improve craft productivity. The research presented here refers to one component of the overall RT 252 research effort. The author of this Thesis was one of the researchers on RT 252. She had a lead role on the development of an index to assess the level of implementation of practices that may improve productivity. The establishment of this index is a key component of the RT 252 research program.

RESEARCH SCOPE

The research team conducted a literature review of the previous relevant research conducted by CII and other organizations on factors affecting productivity and management practices improving productivity. The team identified and selected the management practices and techniques that have a strong positive influence on craft worker productivity by using the experience and knowledge of the members of the research team, which has representatives from owners, contractors, and academic institutions. Then, the research team conducted a survey that involved both owners' and contractors' organizations to rank the management practices according to their potential impact on craft productivity. The involved companies were both CII and non-CII member organizations. From the results of this survey, different weights were attributed to the practices.

RESEARCH OBJECTIVES

The primary objective of this research is to develop an index to measure the implementation level of practices that have the potential to improve craft productivity. The specific objectives include the following:

- Identify initiatives, techniques, or practices that have a significant positive relationship with craft productivity.
- Develop a checklist that a project team can use for determining the productivity practices that need to be implemented during construction.
- Prioritize the identified practices according to their potential impact on craft productivity.
- Perform preliminary tests and analyses of the developed index.

LIMITATIONS

The limitations of the research project arise from the complexity and uniqueness of construction projects:

- The research focuses on industrial construction and technologies specifically relevant to the civil, mechanical, and electrical crafts.
- Some management practices may not be applicable to the whole construction industry due to the nature of construction projects but the index takes that fact into account.
- The research focuses on management practices already developed and well known for having a strong impact on craft worker productivity.

ORGANIZATION OF THE THESIS

The thesis is organized into seven chapters and several appendices containing results of data collections, graphs and surveys packages that were used. Following this introduction chapter, chapter two explains the different steps of the research methodology that was adopted to reach the goal. In Chapter three, some background on practices and factors influencing craft productivity are presented. Chapter four presents a detailed description of the index development process. Chapter five describes the index elements weighting process. Chapter six discusses the preliminary testing process. Chapter seven concludes this thesis summarizing the results and suggesting recommendations for future research.

Chapter 2 – Research Methodology

This chapter gives an overview of the research methodology followed in this research project and the specific research methods, including literature review, score sheet and survey package development methods, implemented in each phase of this project. Figure 1 illustrates the general organization of the research approach.

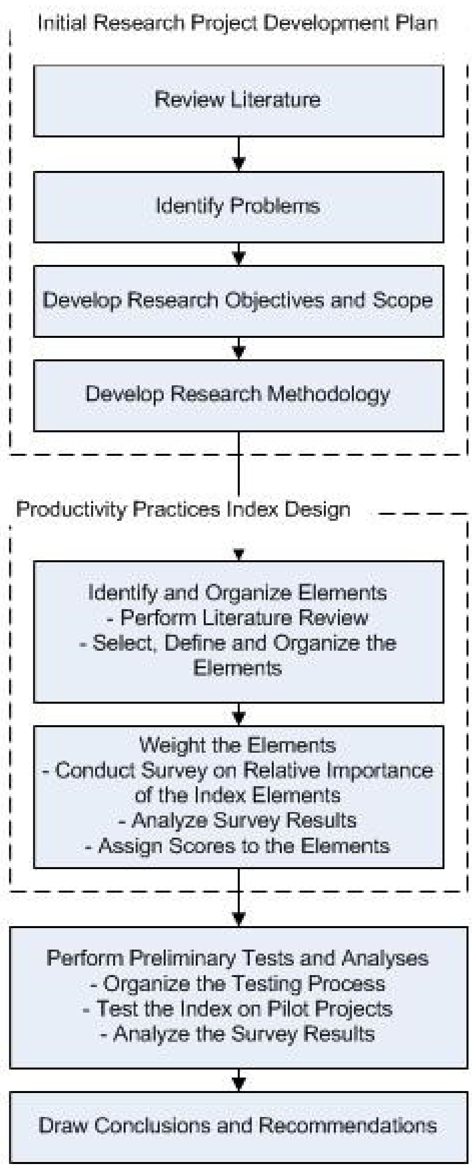

Figure 1 - Research Methodology

As can be seen in the research process flowchart, after completing the initial research project development plan, the research focuses on the development of the index. The development of the index has three main phases: (1) the identification and organization of the index elements; (2) the weighting of the index elements, and (3) the preliminary testing of the index. Both qualitative and quantitative methods were used.

The research project uses two main methods for identifying and organizing craft productivity practices. First, relevant literature is reviewed such as previous CII research programs and non-CII publications that have validated construction management practices that have a significant impact on craft labor productivity. Indeed, an extensive background review was performed on factors affecting labor productivity and practices improving craft productivity. At the same time, RT 252 team members helped to identify the essential successful practices needed to ensure a high craft productivity. Expertise and knowledge of the research team member were used to select and obtain inputs on current construction management practices and methods and particularly to organize the practices into elements, sections and categories. Publications were extensively used to accurately define and describe the index elements. In addition, the research team members reviewed, adjusted and refined the index elements descriptions. As a result, one initial version of the productivity practices index structure was developed, which consists of 53 elements regrouped into 18 sections themselves organized into 6 categories. The sections that are included in each category are similar and related but not the same. The elements were defined and an audit form for each of them was developed. The audit form includes the identified practices that are essential to properly planning and implementing the element. It helps project management team to objectively evaluate the level of planning and implementation of the element.

The following step is to weight the identified elements. The relative influences of the implementation of the selected practices on craft productivity are not obvious. The research team agreed that all the elements were not equally important in regard to their potential impact on craft productivity. These different levels of impact should be reflected in the index. So the index elements needed to be compared with each other. Hence, a sample of construction industry experts was asked to share their experience and knowledge to effectively develop the weights of the elements. Among the different available methods for developing a scoring mechanism of the index elements, the research team adopted the email survey method. They considered that it was the most appropriate way to collect a significant amount of data from experienced experts. Electronic surveys present the advantages of being fast, cost-effective, not influencing participants' answers and having a broad and heterogeneous. They tend to have a higher response rate than mail surveys or interviews. Besides, this method allows participants to answer at their convenience. So, a survey was prepared and sent out to the CII companies involved in this research program. The objective of this survey was to assign weights to the different elements depending on the relative impact on craft productivity. The participants were asked to relatively rank the elements according to their importance using experience, knowledge and lessons learned from previous projects. In assessing the relative importance of a category, a section and an element among the others, the impact of this practice on craft productivity was the main factor considered. A total of 103 forms were collected, 73 from contractors organizations and 30 from owners organizations. Based on previous experiences, the development of the scoring mechanism can be considered as a retrospective method. The forms used for this survey can be found in the Appendix C. The results and participants of this survey are listed in the Appendix D.

The identification, organization of the index and the elements scores development are used to finally design the index. The method involves developing a guide of the implementation of the index. After assigning weights, properly structuring the index, and developing an implementation guide, it is essential to test the index on completed and on-going projects with potential future users. Surveys are probably the most common method to collect data. Among the available survey methods to test the index, the team decided to use mail survey. Projects involved in the CII Benchmarking and Metric program have been targeted for testing the index. The main outputs of the preliminary testing process are to use the index in the construction industry environment, to identify the potential benefits of this index, to plot some graphs, and to identify encouraging trends. This survey aimed to initially and partially test the index on completed projects. The testing process also allows the research team to observe initial trends and perform preliminary analyses of the level of craft productivity implementing the index. The survey package sent to companies is available in the Appendix D. The list of all the participants of this survey is not in this research thesis because of confidentiality issues. Results from this preliminary testing phase are used to refine and review the index.

The scope and methodology limitations of the research are identified and discussed. Finally, this research led to the conclusions and recommendations for future research.

Chapter 3 – Background information

CONSTRUCTION PRODUCTIVITY

Numerous research programs looked into the most effective definition of productivity in the construction industry (Pilcher, 1997; Oglesby et al., 2002). Construction productivity has been defined in so many different ways that sometimes it leads to confusion. Indeed, a wide variety of construction productivity definitions exists. Besides, diverse methods existed to measure it, so it might be difficult to determine whether it has been increasing or decreasing over the past few years.

An economist would define the productivity as the ratio of outputs to inputs. This definition can work for both labor productivity (industry real outcome per work hour) and multifactor productivity (industry real outcome per total cost of inputs – labor, equipment, and materials –). However from a site manager's perspective, the productivity represents, either the performance ratio (e.g. actual quantities installed per estimated quantities installed), or the direct work rate. These divergences are due to the fact that the project manager tries to control his productivity in order to manage it whereas the economist mainly thinks about global aspects.

The complexity and uniqueness of the projects in the construction industry increase the difficulty to standardize the measurement of construction productivity. This fact also explains the difficulty encountered by previous studies to clearly see whether construction productivity has been improving or regressing over the past several years. Besides, even if people use the same productivity definition, the approaches regarding the measurements of outputs and inputs differ from one project to another making it hard to compare productivity data.

The productivity definition used by the CII Benchmarking and Metrics committee is work hours per unit of installed work (e.g.: work hours per linear feet of pipe); thus, the lower the number the better (i.e. the fewer hours needed to complete an activity the better). This definition was established following a research study on productivity measurement conducted by CII in 1983. From this study a manual explaining the basic productivity measurement methods was developed (CII, 1990). The research team 252 adopted CII Benchmarking and Metrics' definition of construction productivity.

FACTORS THAT AFFECT PRODUCTIVITY

Over the last 30 years, the factors affecting labor productivity have received increasing attention within researchers of the construction industry. The Department of Energy (DOE) conducted a survey on 12 nuclear energy-related construction projects. They worked with both craft workers and foremen. The main purpose of this survey was to determine and quantify the diverse factors that both negatively and positively impact construction productivity and workers motivation. From the craftsmen questionnaire surveys, they identified nine major factors and ranked them according to their relative impacts on labor productivity: (1) material availability; (2) tool availability; (3) rework ; (4) overcrowded work area; (5) inspection delays: (6) foremen incompetence: (7) crew interfacing; (8) craft turnover and absenteeism and (9) foremen changes (Borcheding et al 1980; Borcheding and Garner 1981). Despite the fact that this study focuses on industrial projects, these factors are pretty universal, so these results can be generalized to the whole construction industry. However, some others factors as the increase lead time in engineering design are very specialized and unique; and can't be applied to all kinds of construction projects.

Several studies were done on construction labor productivity trends. They tried to explain and understand the causes and implications of these trends. A study reviewed the principal factors affecting construction labor productivity. Six factors were identified: (1) project uniqueness; (2) technology; (3) management; (4) labor organization; (5) real wage trends and (6) construction training. This study also exposed four ways to improve labor productivity through management practices: (1) planning; (2) resource supply and control; (3) supply of information and feedback; and (4) selection of the right people to control certain factors. (Allmon et al, 2000). Consequently, numerous research programs looked into the potential ways to improve management and make it more effective in supporting craft workers on a jobsite.

Few years ago, a survey on productivity drivers (e.g. materials management) and opportunities (e.g. strategic management and planning) was conducted by Rojas and Aramvareekul (Rojas and Aramvareekul, 2003). The broad spectrum of the participants brings credit to this study. The results of this survey point out two main areas that have a huge impact on productivity: (1) management skills and (2) manpower issues (e.g. experience and motivation). The survey analysis of the drivers regrouped the results under four categories: (1) management systems and strategies; (2) manpower: (3) industry environment and (4) external conditions. They also noticed that factors have different impacts on labor productivity. The main finding of this research brings out the controllable characteristic of the labor productivity which represents a huge opportunity for productivity improvements. Thus, the labor productivity is seen as a manageable issue. Moreover, the introduction of innovations helps to improve labor productivity but can't solve all the problems related to it. (Rojas and Aramvareekul, 2003)

In 2003, a survey took an interesting look at the construction productivity impacts related to human, management and external factors (Liberda et al, 2003). Understanding the relationship between construction productivity and project performance is crucial to be able to efficiently address the issues. 51 factors - 8 in the Human category, 35 in the Management category and 8 in the External category - were investigated and prioritized by 20 industry experts. They selected the top 15 factors that have the most significant impact on construction productivity: (1) lack of detailed planning; (2) worker experience and skills; (3) inadequate supervision; (4) worker motivation; (5) non availability of materials; (6) worker attitude and morale; (7) team-spirit of the crew; (8) non availability of information; (9) changes in drawings and specifications; (10) non availability of tools; (11) non availability of equipment; (12) nature of project (size and complexity); (13) lack of procedures for construction methods; (14) changes in contract and (15) congested work area . We can notice that there is no external factor but 3 management factors in the top 5, so this fact confirms the feeling that productivity can be managed and is controllable through management practices (Liberda et al, 2003). This feeling is crucial for construction productivity to be improved by the implementation of management practices.

Klanac and Nelson worked on a research project on factors that cause a variation in construction productivity. The selected factors that have the most important impact on labor productivity are the following: (1) project characteristics; (2) site conditions, (3) project execution; (4) weather effects; (5) supervision effects; (6) management of time;

(7) local labor market conditions and (8) availability of tools and construction equipment (Klanac and Nelson, 2004).

Following the researches on factors affecting productivity, a very interesting recent study was conducted on the workers' perceptions of these factors. The research surveyed about 1,996 craft workers throughout the United States (including foremen and general foremen) to determine the overall priorities of 83 productivity factors according to craftsmen. At the same time, workers were asked to evaluate the overall labor productivity of their project. Besides, this survey was completed by a statistical analysis on the real impact on productivity of factors that were perceived as low influence. The results of this survey show that the following six categories have the greatest impact on labor productivity in priority order: (1) tools and consumables; (2) materials; (3) engineering drawing management; (4) construction equipment availability; (5) supervisor direction and (6) safety. Finally this study raised a very important point about workers motivations. Workers liked that the research program had an interest in their points of view; and tried to make them feel better by taking into account their comments and feedback. This fact confirms the huge influence of management practices on labor productivity. However, this survey reveals that depending on trades the impacts of the categories are different, so we should take this into account for future studies when using craft workers inputs (Dai et al, 2009).

Thus, despite several studies conducted on factors affecting construction productivity, researchers have not accorded on a general checklist of factors that have a substantial impact on labor productivity. Besides absolutely no assessment method on the impacts of the factors affecting craft productivity exists. This could be very practical for a management team to eliminate negative impact factors and consequently improve labor productivity.

MANAGEMENT PRACTICES THAT AFFECT CONSTRUCTION PRODUCTIVITY

In 1986, Professor Tucker published an article on the management of construction productivity. He points out the many opportunities for productivity improvement in the management and support services area. Some areas for potential improvement were suggested, such as project planning, client involvement, communication among project players, design, constructability, and technology (Tucker, 1986).Likewise, Liou and Borcherding advised "Productivity measurement is not a one-time task. Continuous measurement and comparison with other projects or companies are keys to productivity improvement." (Liou and Borcheding, 1986). Besides, the evaluation of performance on a regular basis is crucial to effectively manage construction productivity. A factor model of construction productivity was developed and validated in 1987 by Thomas and Yiakoumis. The results of this study gave a frame to quantify the effects of numerous factors on productivity.

A study conducted in 2003 looked into the key performance indicators which represent the management methods helping to control productivity and assess construction performance. The main objective of this research was to identify the key performance indicators of the construction industry that can be useful at the construction executive and project management levels. The broad spectrum of the participants, in terms of construction industries and construction companies (contractors, owners, consultants), confirms the large impact of the selected key performance indicators. They are six: (1) quality control; (2) on-time completion; (3) cost; (4) safety; (5) $/unit and (6) units/man-hours. But some differences still exist, indeed the manager experience, the level of management and the industry sector influence those performance factors (Cox et al, 2003).

Over the world, researches have been conducted on effective management techniques that motivate employees. In China, construction workers were surveyed on their motivations at work. They retained six management practices that have a huge impact on workers motivation and consequently on labor productivity: (1) proper human resource management and job design; (2) life-long learning programs; (3) open-door communication; (4) effective rewarding system; (5) diverse and contingency style of leadership and (6) empowering and valuing employees (Lam and Tang, 2003).

A model to estimate the productivity utilizing all the possible factors was developed in 2006 by Hee-sung Park. In order to design this model they did an extensive literature review in two major areas: productivity measurement issues and factors affecting construction productivity. Form this effort; five categories of factors were highlighted: (1) scheduled overtime; (2) change orders; (3) materials management; (4) weather and (5) human factors. This productivity estimation model takes into account the effects of management efforts and environment factors of the construction project. The research focused on 14 environment factors: (1) weather; (2) labor skill; (3) labor availability; (4) materials availability; (5) site conditions; (6) project complexity; (7) regulatory requirements; (8) project team experience; (9) project team turnover; (10) detailed engineering design location; (11) business market conditions; (12) absenteeism; (13) technology use and (14) human factor. About the management factors, they focused on 8 CII Best Practices: (1) pre-project planning; (2) change management; (3)

constructability; (4) materials management; (5) zero accident techniques; (6) quality management; (7) team building and (8) automation and integration technology. Yet, this model is incomplete so further research is needed. This survey concludes on the fact that construction productivity depends on projects environments, characteristics and level of implementation of management practices (Park, 2006).

Productivity improvement can be viewed as a function of management as changes for improvement can only be implemented at management level (Parham and Zheng, 2006). The research project concluded on very interesting remarks. First, the construction productivity needs to be measured as accurately as possible. Then, project managers should understand the weaknesses and the strengths of labor productivity measurements in order to effectively manage it and properly interpret the trends.

Hemanta Doloi looked at the potential improvements in labor productivity from a management perspective. This study aimed to highlight the reasons of low labor productivity and how to overcome the issues caused by it. Thus, this research identifies and analyzes the prevalent management issues affecting labor productivity. The survey package was made up of a questionnaire drawn from an extensive literature review. The research results point out three major factors that have a huge influence on construction productivity: (1) pre-planning; (2) programming and (3) productivity bonuses (incentives) (Hemanta Doloi, 2008).

Thus, many studies conclude that poor management practices as among the main causes of low labor productivity. Moreover, huge opportunities for productivity improvements exist in the management area, that just wait for being implemented.

CONSTRUCTION PRODUCTIVITY MEASUREMENT

One of the first productivity models was developed in 1976 by Adrian and Boyer. It was called the Method Productivity Delay Model (MPDM) and was designed to measure, foresee and improve productivity of construction practices (Adrian and Boyer, 1976). To improve productivity, means of measurement and comparison of performance are expressed in the project report of The Business Roundtable Industry Cost Effectiveness (CICE) in 1982. Following this report, Weber and Lippiatt did an extensive literature review on all the existing methods for measuring both single and total factor construction productivity. Work studies such as work sampling, foreman delay surveys, five-minute rating and group timing techniques caught their attention (Weber and Lippiatt, 1983). Reliable engineering productivity measurement is essential to control and manage project performance.

In 1987 Harrington stated "measurement is the first step that leads to control and eventually improvement", and three years later the Construction Industry Institute (CII) developed a productivity measurement system. This tool includes reporting, outputs and inputs systems, and system that measure the performance to evaluate labor productivity (CII, 1990).

A strong need for standardization was expressed. So in 2001, CII conducted a survey to develop a standard construction productivity benchmarking data collection tool. The result of this research program was the development of the Construction Productivity Metrics Systems (CPMS), which contains 56 measuring elements organized into seven major categories: (1) concrete; (2) structural steel; (3) electrical; (4) piping; (5)

instrumentation; (6) equipment and (7) insulation . They also validated the usefulness of metrics to collect standard construction productivity data (Park et al, 2005). In parallel with this research program, another one developed norms, called engineering productivity metrics, to accurately measure engineering productivity (CII, 2001).

A "stratified model of factors affecting productivity" was developed and validated through case studies; this model takes into account the levels of impact of the selected factors (activity level, work environment, project level) (Ying, 2004). Up to now, the current productivity measurement systems has focused on micro level activities to manage daily, weekly or monthly during the construction phase.

LITERATURE REVIEW CONCLUSIONS

The existing literature gave a strong base to build on. First, it gave some background of construction productivity and how this notion has evolved over the past few decades. Then, some specific significant factors affecting craft productivity were identified. A survey analyzing the workers' perceptions of those factors led to more specifically both the positive and negative impacts of management practices on construction productivity. Finally, the different methods and techniques to measure construction productivity were exposed. From this literature review considerable evidence surfaced: there is a strong need of a study that establishes the best management practices for craft productivity improvements. It is also critical to develop an Index to assess the level of implementation of these practices.

Chapter 4 – Development of the Productivity Practice Index

OVERVIEW

The proposed Productivity Practice Index is intended to measure the implementation level of practices that have the potential to improve craft productivity: one can only improve what can be measured. The Productivity Practice Index is envisioned as a tool to assist a project manager or project superintendent in planning jobsite activities and executing management practices that are widely accepted throughout the construction industry as having a positive effect on craft worker productivity. Multiple practices are acknowledged to improve labor productivity but are seldom implemented due to lack of knowledge of management practices, lack of organization, apathy of those on jobsites, or many other diverse reasons. This index aims to help site management team to better plan and effectively implement site practices, from one project to another, that have been known for years to improve craft productivity.

The Productivity Practice Index is indented to be used during the whole life of construction projects, from the conceptual design and scope of definition of pre-project planning trough the engineering and design, procurement, and construction of the execution and control phase. The earlier in the project development the tool is used, the greater the opportunities are to positively impact the project outcomes. The earlier the decisions and changes are made the lower negative impacts they have on project cost and schedule. This index should also help site managers to identify and select management practices that need to be implemented on the construction site. The index outlines a new process for building the foundation of the essential practices needed to ensure a high level of labor productivity.

The Productivity Practice Index is envisioned as:

- A listing of the essential elements that need to be planned and implemented in a project.
- A checklist that a project team can use for determining the level of implementation of the productivity practices.
- A listing to develop strategies for the implementation of productivity practices.

PRODUCTIVITY PRACTICE INDEX DEVELOPMENT

The development of the index began by using the knowledge and experience of the members of the research team and studies that validated construction practices that have a significant positive impact on craft worker productivity. From this development effort, six categories were highlighted: (1) Materials Management; (2) Equipment Logistics; (3) Craft Information Systems; (4) Human Resources Management; (5) Construction Methods and (6) Environmental Safety and Health.

Elements of the index correspond to construction practices. Each practice is organized into sections that include similar practices and has an audit form. Between two and four sections are regrouped into categories. Each category focuses on factors that studies recognized as having significant impacts on craft productivity.

Briefly, materials management helps to plan the effective materials organization on site, materials delivery and inventory, and materials procurement. Equipment logistics focuses on the management of equipment, tools and consumables needed to perform on site activities. Craft information systems make sure craft worker have access to necessary information to complete the project. Human resources management focuses on training, incentives, motivation, behaviors of the craft workers. Construction methods category is self explanatory. And last but not least, environmental safety and health concerns the planning and implementation of a high safety level on the project.

THE SIX PRODUCTIVITY PRACTICE INDEX CATEGORIES

Materials Management

Numerous previous CII research studies have brought out the significant role of the implementation of an effective materials management in improving craft productivity. The first one was conducted in 1986; Research Team 7 (RT 7), Materials Management, highlighted the significant potential benefits of implementing materials management systems for craft labor productivity. In 2006, Research Team 215 (RT 215), Work View of Construction Productivity, pointed out that onsite materials management was considered as one of the most important factors affecting construction productivity among CII member companies. RT 215 highly recommended that future research examines the potential ways to improve on-site materials availability. Then in 2008, Research Team 240 (RT 240), Leveraging Technology to Improve Construction Productivity, conducted case studies on a new automated materials tracking technology. The results showed that material management is highly improved by the use of automated materials identification and localization technology. Besides, various other research projects have pointed out the significant importance of the implementation of an effective material management practice. For example, many publications on the potential effects of housekeeping, organization of storage areas, material procurement planning, and material availability on craft productivity can be found. More recently, Research Team 257 (RT 257), Global Procurement & Materials Management Best Practice Refresh, found out that the implementation of effective material management practices leads to costs reduction, more predictable project outcomes, craft productivity and quality improvement.

Equipment Logistics

This research program considers construction machinery and tools as equipment. Research Team 143 (RT 143), Craft Productivity Improvement, investigated the impact of extra construction equipment on craft productivity surveying piping and electrical crafts. RT 143 pointed out that increasing the availability of construction equipment improves labor productivity. One of the recommendations from RT 143 regarding the availability of construction equipment is the development of a buffer of extra construction equipment to handle the periods of high demand. Moreover, the onsite management of construction equipment had negative impacts on labor productivity. Besides, RT 215 determined construction equipment as one of the major factors affecting construction productivity according to workers. Some other research efforts on construction equipment suggested strategies such as loss-control systems for on-site tools to solve this issue.

Craft Information Systems

A series of previous studies have pointed out the huge importance of communication within a construction project team. Workers need to have access to accurate project information. Indeed, workers should have access to relevant and accurate project information related to the activities they have to perform when they need it. The appropriate access to this information can increasingly enhance both labor productivity and worker motivation. For instance, quality requirements, project and tasks schedules, project safety guidelines, and milestones of activities can reduce rework rates and help workers to effectively plan the different tasks. The availability of project information is definitely something that can highly increase the worker productive time. Advanced project information management systems allow an effective integration of work processes. Besides, demand-based resource management represents a huge opportunity to improve craft productivity; indeed such processes make sure craft workers have the necessary information to perform their tasks. Appropriate accesses to tasks guidance mechanisms, improvements in crafts coordination, and project state intelligence result in significant increases in construction productivity. Lately, a Workface planning model was developed by the Construction Owners Association of Alberta (COAA). Research Team 125 (RT 125), Information Management Impacts, and Research Team 258 (RT 258), Information Integration to Improve Capital Project Performance, worked on information integration. It represents a huge challenge but at the same time if implemented it increases quality and reduces cost. Information needs to be shared throughout the entire construction project team. So it has to be integrated and easily exchanged between the actors involved in the construction project to have significant impact on project cost and schedule.

Human Resource Management

The shortage of skilled labor is one of the major challenges that the construction industry has been facing over the past several years. Fortunately, it has been mainly offset by the huge advancements in technologies, work packaging, and construction site organization. But, we can't keep on hiding consistent evidence that the shortage of skilled craft worked is one of the most difficult issues that construction industry is facing and doesn't succeed in overcoming it. And even of all the advancements made in this industry, this can't by itself offset this shortage. Many reasons have been heard to explain this shortage such as the decline of construction real wages, construction industry reputation, poor construction work environment, work force demographics, or lack of adequate training opportunities. Improving craft worker motivation, satisfaction, and encouraging trust between workers and supervisors might be an appropriate and adequate solution to the labor shortage issue. Indeed a strong behavioral dimension is present, hidden under this shortage issue. These improvements and encouragements are crucial to create a friendly working atmosphere where workers feel listened, valued and trusted. This work environment provides improvement in craft productivity.

Research Team 231 (RT 231), Construction Industry Craft Training, pointed out the significant benefits from craft training, such as improvements in craft labor productivity and reductions in turnover and absenteeism. Besides the shortage of certified workers encourages the establishment of a craft training program. Research Team 140 (RT 140), Project Incentives, developed a tool to help companies to implement the adequate incentive plan that results in significant craft labor productivity improvements.

One of the most important recommendations from previous CII research efforts was to consider: involving craft workers in project planning as much as possible to increase worker motivation, establishing open communication between craft workers and management team to build a relationship based on trust for both good and bad news or comments to easily be conveyed, enhancing the benefits of training by utilizing and rewarding craft skill certifications, pairing beginners with experienced workers to set up mentoring systems, encouraging foremen and superintendents to participate in supervisory training programs, reducing competition among project superintendents to promote a more collaborative environment.

Construction Methods

The organization of construction work has been inspired by the Ford or Taylor assembly line, or even Alfred P. Sloan's ideas on industrialization. Other useful sources such as just-in time delivery strategies, the lean construction philosophy, and methods of prefabrication, preassembly, and modularization helped to establish the principal methods of construction work. Prior CII research efforts resulted in the development of specific tools, concepts and methods such as short interval planning methods, work packaging, constructability, multi-skilling, design for maintainability, innovative crew scheduling, workforce management strategies, or even high performance work teams. All those techniques have influenced differently the organization of the construction work.

The Industrial Revolution founding idea was to use automation and advanced technology to eliminate hazardous and boring work for workers to fulfill higher needs. Thus, workers' skills were increasing. They replaced manual work by automated machines leading to a huge increase of productivity for the industry and a significant improvement in the quality of life for workers. The discovery and development of hydraulic power in the 1950s helped the construction industry to improve their productivity by introduction new more efficient construction equipments. Several years ago, the advancements made in both power and control, due to materials of better quality and the development of computer technologies, have provided smaller, more adaptable and skilled equipments in the construction industry. Skid steer machines, orbital welding tools, nail guns, and battery powered hand tools are relevant example of these breakthroughs or innovations technologies in construction equipments. The introduction of these new equipments has had a significant positive impact on craft productivity. The last few years, very sophisticated equipments have come into being leading to substitute more machines for workers.

Environmental Safety and Health

In 1990, CII conducted a research program, Zero Accident Task Force, to identify techniques that were implemented by contractors to achieve zero accidents. Research Team 160 (RT 160), Making Zero Accidents a Reality, identified nine key areas that lead to better safety performance. The most important are safety orientation and training, safety planning, safety evaluation followed by reward/recognition (incentives), and drugs and alcohol testing. Research Team 101 (RT 101), Design for Safety, pointed out the usefulness of toolbox safety meetings. Besides, CII member companies have made environmental safety and health performance their number one priority. Thus, they excel in this domain. Safer projects are more productive, it seems to be an obvious fact. However, very few research programs looked into the relationship between construction productivity and the implementation of safety practices. Dr. Jimmie Hinze is one of the few professors who conducted a research program on safety practices. He highlighted that superintendents with the highest-rated ability to complete projects on schedule and under budget were also those with the best safety records. During the construction phase, projects with better safety records are also the ones with better safety planning. There seems to be a strong relationship between safety planning and project's planning for managing labor productivity but not any study has quantified this relationship. There is a strong need for future research. Studies need to be conducted to assess the relationship between safety practices and construction productivity.

PRODUCTIVITY PRACTICES INDEX ELEMENTS DEFINITION

Categories, Sections and Elements

The Productivity Practices Index includes 6 categories which contains 18 sections. Those sections were chosen based on the expertise of the research team and research efforts of the past. Each section contains between 1 to 8 elements that correspond to best practices recognized in the construction industry. Table 1, Productivity Practice Index Categories, Sections and Elements, shows each category and their sections and elements.

I - MATERIALS MANAGEMENT
A. Material Management Systems Best Practices
- A1. Project team material status database
- A2. On-site material tracking technology
- A3. Material delivery schedule
- A4. Procurement plan for materials and equipment

B. Receipt and Inspection of Materials Best Practices
- B1. Material inspection process
- B2. Material inspection team
- B3. Post receipt preservation and maintenance

II - EQUIPMENT LOGISTICS
A. Site Tool Management Best Practices
- A1. Site tool and consumables management strategy
- A2. Tool tracking systems
- A3. On-Site tool maintenance
- A4. Control system for tool delays

B. Machinery Availability Best Practices
- B1. Construction machinery productivity analysis
- B2. Equipment maintenance

III - CRAFT INFORMATION SYSTEMS
A. Short Interval Planning Best Practices
- A1. Short Interval Planning

B. Work Face Planning Best Practices
- B1. Well defined scope of work
- B2. Utilization of software to assist in generating work packages
- B3. Project model requirements
- B4. Dedicated Planner
- B5. Identify required permitting
- B6. Engineering Work Packages (EWP)
- B7. Construction Work Packages (CWP)
- B8. Field Installation Work Packages (FIWP)

C. Constructability Review Best Practices
- C1. Design readiness for construction
- C2. PPMOF evaluation

IV - HUMAN RESOURCE MANAGEMENT
A. Training Best Practices
- A1. Trades technical training
- A2. Career development

B. Behavior Best Practices
- B1. Nonfinancial Incentive Programs
- B2. Financial Incentive Programs
- B3. Social Activities

C. Organizational Structure Best Practices
- C1. Maintain Stability of Organization Structure
- C2. Clear Delegation of Responsibility

D. Employment Plan Best Practices
- D1. Retention Plan For Experienced Personnel
- D2. Exit Interview

V - CONSTRUCTION METHODS
A. Sequence and Scheduling of Work Best Practices
- A1. Integrated Schedule Using Critical Path Method (CPM)
- A2. Work Schedule Strategies
- A3. Schedule Execution and Management

B .Start-up, Commission, and Turnover Best Practices
- B1. Planning for Start-Up
- B2. Testing Procedures
- B3. System Turnover Procedure

C. New Technology Investigation Best Practices
- C1. New equipment investigation
- C2. New information system investigation
- C3. New materials technologies Investigation

D. Site Layout Plan Best Practices
- D1. Dynamic site layout plan
- D2. Site security plan
- D3. Equipment positioning strategy

VI - ENVIRONMENTAL SAFETY AND HEALTH
A. Job Safety Best Practices
- A1. Zero Accident Techniques
- A2. Task Safety Analysis
- A3. Identification of Potential Hazards
- A4. Housekeeping
- A5. System test hazards planning

B. Substance Abuse Programs Best Practices
- B1. Organization drug testing

C. Safety Training and Orientation Best Practices
- C1. OSHA Compliance Training
- C2. Toolbox safety meeting

Table 1 – Productivity Practices Index Categories, Sections and Elements (CII RT-252, 2009)

Category I – Materials Management

Materials Management is made up of two subcategories: Materials Management Systems and Receipt and Inspection Materials. Below, figure 2 show the organization of Material Management category.

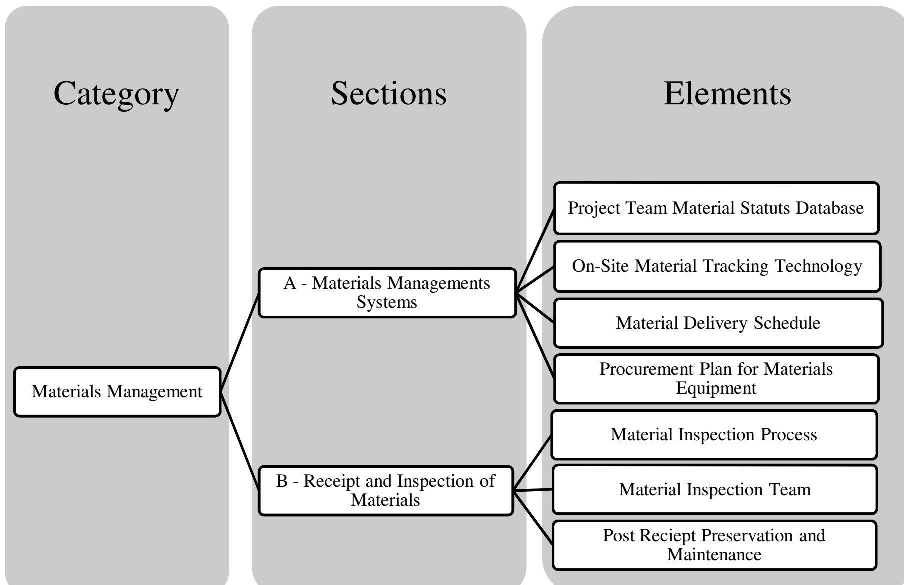

Figure 2 - Organizational Structure of Materials Management

Previous research programs were conducted on the impacts on construction projects of efficient material management plans, and these programs found out that properly implemented, material management plans have a significant positive impact on craft labor productivity. In 1986, CII conducted a study the impact of materials management plans on cost effectiveness and labor productivity. This study involved 20 large industrial projects and proved that formal material program have a significant positive influence on both cost effectiveness and labor productivity in construction projects. (CII, 1986)

This study was followed in 1989 by a research program leaded by Thomas et al. on the effects of material management systems on construction productivity. The results point out that the lack of an efficient material management plan can lead to adverse conditions such as additional work hours. Those adverse conditions significantly reduce labor productivity. Lack of material management system involves shortage of materials, lack of housekeeping, planning for material delivery, documentation material delivery schedules, and organization of storage areas (Thomas et al., 1989). 6 years later, Thomas and Napolitan, investigated productivity data of 3 industrial projects and concluded that the lack of materials on site to perform activities reduces the craft output by 30% (Thomas and Napolitan, 1995). Ten years ago, Thomas and Sanvido conducted another study where they also investigated productivity data of 3 construction projects. This time, they highlighted that improper material management can decrease labor productivity by 50% (Thomas and Sanvido, 2000).

Materials Management Systems

This section is defined as the use of integrated set of systems used to identify, track report and facilitate control of project materials. The successes of material management programs are ensured by the implementation of certain practices. Proper storage allows quicker locating of materials, and easier lifting and transportation of materials. Advancements in technology help to improve material management systems. Global Positioning System (GPS) and Radio Frequency Identification (RFID) Systems are examples of technologies that can improve labor productivity by reducing the amount of time spent locating materials and lost materials, and decreasing work disruptions. Numerous studies on tracking technology have showed benefits such as time saving from implementing tracking technology plan on site (Caldas et al., 2006; Ergen, 2006; Grau et al, 2009).

Materials management plans address materials procurement, which includes the materials delivery schedule. Besides, material delivery schedule must coincide with project work schedule to be most effective to prevent trades interferences. Properly planned, this schedule can increasingly improve labor productivity (Thomas et al., 1999). Moreover, Rojas and Aramvareekul ranked procurement management as the fifth most powerful opportunities (out of 16) to improve craft labor productivity (Rojas and Aramvareekul, 2003).

This section contains 4 elements:

- *Project Team Material Status Database* is an automated system that manages aspects such as the delivery date, date of installation, and storage location of all material used on the project.
- *On-site Material Tracking Technology* is the system that the project team uses to track and locate material that is delivered to the project site.
- *Material Delivery Schedule* is a documented schedule of when material deliveries occur and when the material is needed to be on site for installation.
- *Procurement Plan for Materials and Equipment* is the planning for the acquisition of all material, equipment, tools, and consumables that are necessary to complete the project in an organized and timely manner.

Receipt and Inspection of Materials

Receipt and Information of Materials is defined as the examination of the materials before acceptance to note completeness of the delivery and any obvious external damage of the delivered materials. The following are the 3 elements of this section:

- *Material Inspection Process* is the documented plan for the inspection of all materials delivered to the project site.
- *Material Inspection Team* is the employees that are hired to perform the material inspection process
- *Post Receipt Preservation and Maintenance* is the upkeep, inventory, and inspection of material stored on the project site

Category II - Equipment Logistics

Equipment Logistic is made up of two sections: Site Tool Management and Machinery Availability. Below, figure 3 show the organization of Equipment Logistics category.

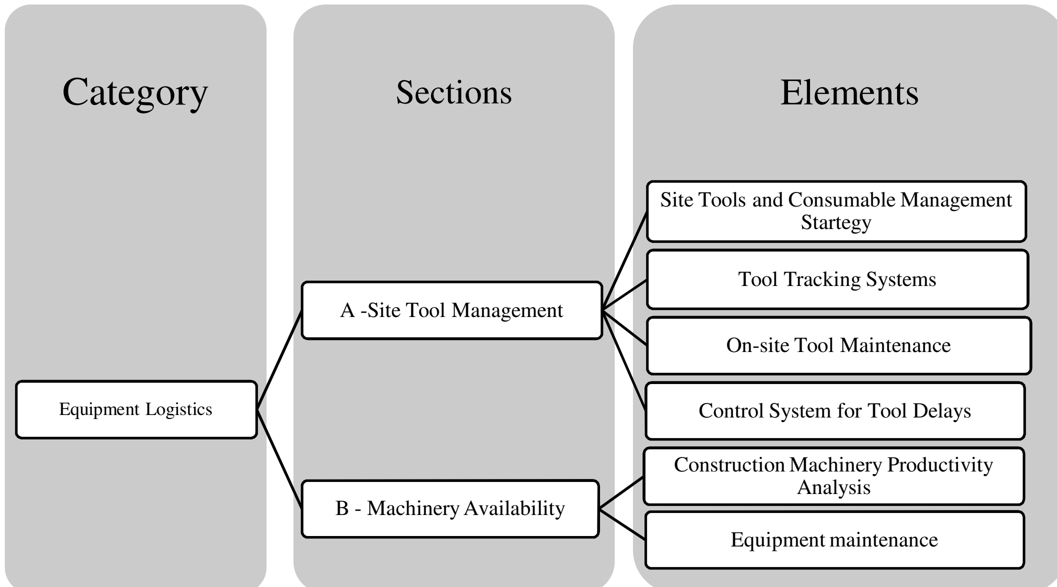

Figure 3 - Organizational Structure of Equipment Logistics

The Voice of the Worker Index research project conducted between 2004 and 2006 by CII determined that the availability of appropriate construction equipment and tools on jobsites is the factor which as the most significant impact on craft labor productivity (CII, 2006). Besides Dai and Goodrum show that the number on factor that affect craft labor productivity is “I have to wait for people and/or equipment to move the material I need” (Dai and Goodrum, 2005).

Site Tool Management

Site tool management is the planning and organization of all tools used on the project. Tools include saws, hammers, grinders, or other equipment that is operated and guided by hand as well as the power sources required for their operation. Findings by a Department of Energy (DOE) study and Dai et al. support the importance of site tool management plan to ensure tools are present on site, stored in a location that is organized and easy to locate, and in proper condition to perform designated tasks. The following are the 4 elements of this section:

- *Site Tool and Consumables Management Strategy* is the development of a plan to acquire, organize, store, inventory, and maintain tools and consumables that are necessary to complete the project.
- *Tool Tracking Systems* is a formal plan to monitor the location and/or responsible parties for tools when they are checked out of the storage area for use in the field.
- *On Site Tool Maintenance* is the practice of maintaining all tools necessary on the project to ensure that they are performing up to specifications.
- *Control Systems for Tools Delays* is a plan for determining the delays to productivity that are caused by craft workers waiting for tools, lack of tools, and the tool not performing its designated task up to specifications.

Machinery Availability

Machinery availability is defined as the planning and organization of all construction equipment that may be used on site. This practice ensures the availability, effective maintenance and optimized location of earthwork, lifting and transporting equipment. The following are the 2 elements of this section:

- *Construction Machinery Productivity Analysis* is determining and understanding the cost of using a piece of equipment and the improvement of productivity due to the use of the equipment.
- *Equipment Maintenance* is the practice of maintaining equipment used on jobsite to ensure that all equipment is performing at optimum levels.

Category III – Craft Information Systems

Craft Information Systems is composed of three sections: Short Interval Planning, Work Face Planning, and Constructability Review. Below, figure 4 show the organization of Craft Information Systems category.

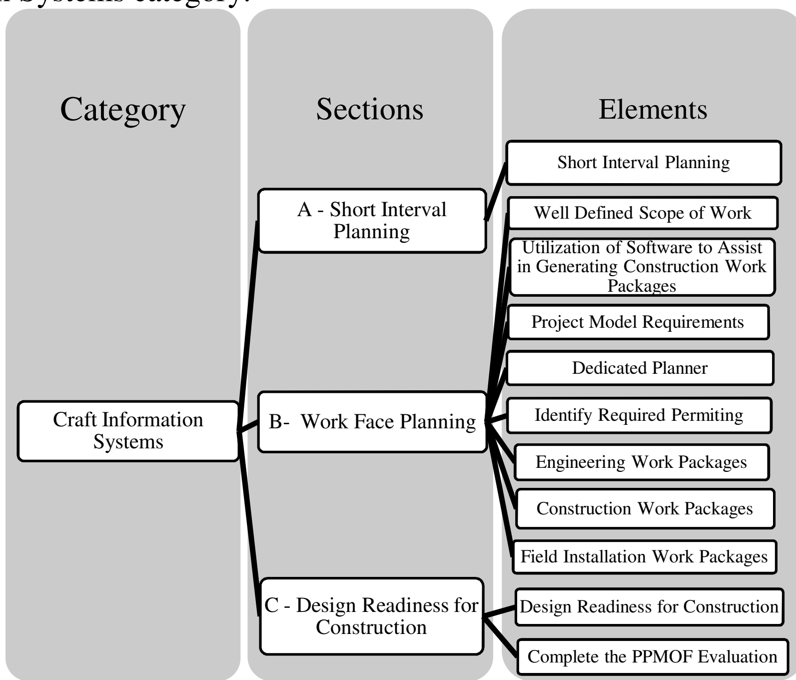

Figure 4 - Organizational Structure of Craft Information Systems

Multiple parties represent one of the big challenges of construction projects. The main challenge is to integrate all these parties and aligned their specific goals with the project goals to ensure project success. Efficient coordination between parties (contractor, owner, government regulation officials, architects, and engineers) is crucial in large projects. Properly panned information systems definitely improve communication between parties. Thus, craft workers have access to information they need to perform their tasks which improves their efficiency. In 2003, Libertad et al. conducted a survey on the importance of the availability of project information for craft workers. They interviewed about 20 industry experts, and the results showed that the lack of information and detail planning was one of the most important factors affecting craft labor productivity (Libertad et al., 2003).

Short Interval Planning

Short Interval Planning is defined as a reactive plan in response to updated progress. It is creating short term construction schedule that include tasks performed, craft workers needed on site, duration of each task, and the required materials, tools, and equipment. There is only one element in that section which is Short Interval Planning.

Work Face Planning

Work Face planning is defined as the adequate planning of the construction work face. This planning allows ensuring that the appropriate organization and delivery of all necessary elements in a timely manner. Thus, craft workers are able to perform quality work in a safe, effective, and efficient manner (COOA, 2008). The following are the 8 elements of this section:

- *Well Defined Scope of Work* is a clear description of the basic requirements, goals, timeframe, and the owner's vision of the project.
- *Utilization of Software to Assist in Generating Work Packages* is using automated software for assisting in creating schedules for project tasks and material deliveries and identifying the necessary materials needed to complete task.
- *Project Model Requirements* is a scaled physical or digital representation of the product that is built.
- *Dedicated Planner* is a person that is appointed to plan, organize, and approve all work activities that take place on the construction site.

- *Identify Required Permitting* is the identification of the official project execution authorization documents from the city, county, state, nation, and owner.
- *Engineering Work Packages* defines a scope of work to support construction in the form of drawings, procurement deliverables, specifications and vendor support.
- *Construction Work Packages* defines in detail a specific scope of work and should include a budget and schedule that can be compared with actual performance.
- *Field Installation Work Packages* (FIWP) is a detailed execution plan that ensures all elements necessary to complete the FIWP scope are organized and delivered before work starts.

Constructability Review

Constructability Review is defined as the incorporation of construction knowledge in the creation of the design documents. Constructability reviews allow experienced contractors to take part in the design decisions which have significant impacts on project outcomes. Indeed, changes orders have a negative impact on labor productivity, so the earlier the changes are made the better. Research proved that constructability reviews provide potential improvement in many different areas such as labor productivity. These reviews encourage simplified design and the utilization of optimal construction systems that lead to reduction of work hours. The following are the 2 elements of this section:

- *Design Readiness for Construction* is a review of the design documents to ensure they are correct and complete.

- *Complete the PPMOF Evaluation* is self explanatory.

Category IV - Human Resource Management

Human Resource Management is made up of four sections: Training and Development; Behavior; Maintain Organizational Structure and Employment. Below, Figure 5 shows the organizational structure of Human Resource Management category.

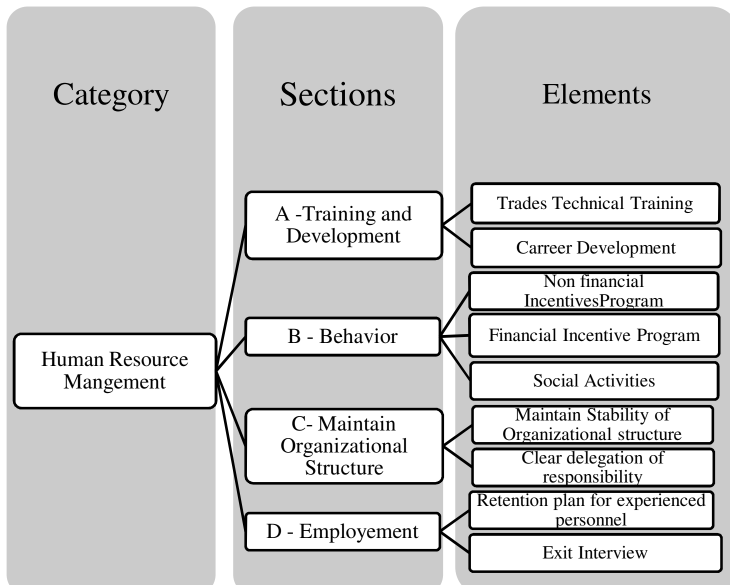

Figure 5 - Organizational Structure of Human Resource Management

Human Resource Management ensures proper craft training, organization, behavior and moral to successfully complete the construction project.

Training and Development

Training and Development is defined as the development of craft skills through training, to help ensure that workers have the proper skills to effectively and efficiently perform their designated tasks. Previous studies conducted by Rojas and Aramvareekul involving a broad spectrum of participants highlighted the huge potential of craft training in improving craft productivity, it represents one of the most promising opportunities. Multiple benefits of craft training that can be expected because it reduces absenteeism, turnover and rework (Rojas and Aramvareekul, 2003). The following are the 2 elements of this section:

- *Trades Technical Training* prepares workers to perform a specific trade and cover how to use the proper tools, installation process and safety requirement.
- *Career Development* is a long term career path including training, advancement, and promotion options for the craft workers.

Behavior

Behavior is defined as addressing both craft workers motivation and satisfaction for them to enjoy their work. Motivation drives workers behaviors on jobsite. Surveys conducted by Rojas and Aramvareekul determined that motivation is one of the most important productivity drivers. Other studies looked into the different practices to effectively motivate workers. Both financial and non-financial incentive programs have proved their efficiency if effectively implemented and managed (frequent evaluation and awards) in improving craft labor productivity and performance (Goodrum and Gangwar, 2004). The following are the 3 elements of this section:

- *Nonfinancial Incentive Programs* are formal programs that track and record craft worker safety performance and frequently reward craft workers with non-monetary rewards.
- *Financial Incentive Programs* are formal programs that track and record craft worker safety performance and frequently reward craft workers with monetary rewards.

- *Social Activities* are company or project planned activities involving craft workers outside of the work setting.

Organizational Structure

Organizational structure is defined as the development of a clearly defined line of authority on the jobsite that reduces the cycle tome of the processing and exchange of information. The following are the 2 element of this section:

- *Maintain Stability of Organizational Structure* is working towards a stable organizational structure by avoiding changes in key personnel on a project.
- *Clear Delegation of Responsibility* is a defined structure of project actors' roles and responsibilities.

Employment

Employment is defined as the strategy of employment for retaining productive, effective and experienced workers. Rojas and Aramvareekul pointed out that the experience of a craft worker has a significant positive impact on labor productivity. Thus, the creation of a formal plan to retain experienced and skilled craft workers represents a promising opportunity for improving craft labor productivity. The following are the 2 elements of this section:

- *Retention Plan for Experienced Personnel* is a company/project specific program in place to retain highly skilled and experienced craft workers who are currently employed.
- *Exit Interview* is an interview with craft workers that leave the company/project to determine the reasons for leaving.

Category V - Construction Methods

Construction Methods is composed of 4 sections: Sequencing and Scheduling of Work; Start-up, Commission and Turnover Plan; New Product Investigation; Site Layout Plan. Below, figure 6 shows the organizational structure of Construction Methods Category.

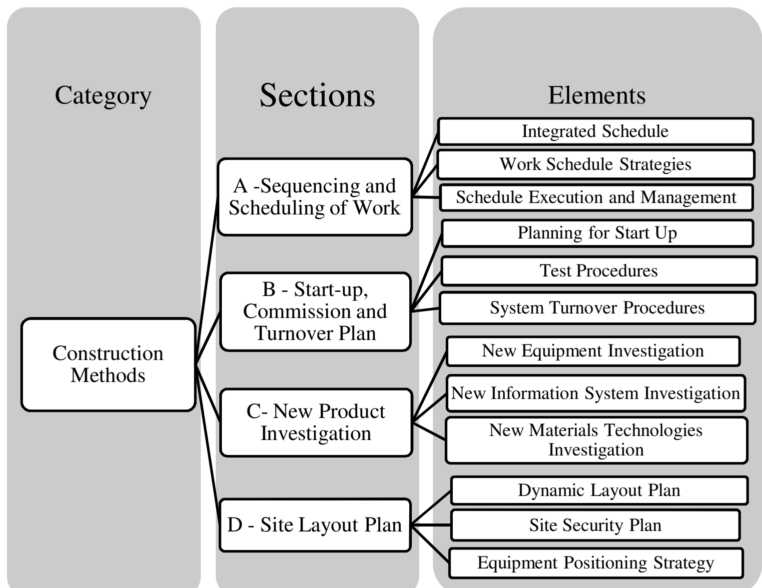

Figure 6 - Organizational Structure of Construction Methods

Construction methods used for the completion of a project play an important role in project success. The incorporation of technologies in construction methods is crucial for the improvement of labor productivity (Rojas and Aramvareekul, 2003).

Sequence and Scheduling of Work

Sequence and Scheduling of Work is defined as the development of the logic and the time required for construction including when equipment, materials, and information will be needed by crafts. To ensure that the project completion date is met, the project team develops an overall, daily, weekly and monthly schedules. Forward and backward techniques help the team to effectively plan activities to avoid negative impacts on completion date. The following are the 3 elements of this section:

- *Integrated Schedule* is creating a schedule for all project activities using forward and backward techniques.
- *Work Schedule Strategies* is the specific work schedule approach used on the project.
- *Schedule Execution and Management* is the oversight of the work performed to meet project schedule, as well as updating the schedule and measuring project progress.

Start-Up, Commission, and Turnover Plan

Start-Up, Commission and Turnover Plan is defined as the development of a plan for the start-up, commissioning and turnover of the finished project. Start-up phase is a delicate task and can easily lead to project failure. Lack of management commitment, start-up objectives and execution plans result in start-up failures. The participation from all project stakeholders is seen as the most effective way to address start-up planning. CII previous research programs identified 8 criteria that increase the chances of start-up success: product quality and quantity, schedule and safety performance, environmental compliance, operations team performance, impact of ongoing operations, and level of stress experienced by the start-up team (O'Connor, 1997). The following are the 3 elements of this section:

- Planning for Start-Up is "the traditional phase between plant construction completion and commercial operations, including all the activities that bridge these two phases" (O'Connor, 1997).
- *Testing Procedures* are protocols designated to test project components.

- *System Turnover Procedure* is the transfer to the owner of the built facility.

New Technology Investigation

New Technology Investigation is defined as the investigation and adoption of innovative and cost-effective materials, equipment or technology` available in the market that potentially improve labor productivity. The last few years, advancements in technology in the construction industry have been significant, but their impacts on labor productivity have been difficulty measured. In 2006, CII created a research team to focus on the benefits of technology improvements in the construction industry. From this research effort, four factors that positively impact labor productivity were identified: amplification of human energy, level of control, functional range and information processing. Besides another study highlighted three factors that affected productivity: modularization, reduction in unit weight and installation flexibility (Caldas et al., 2009). The following are the 3 elements of this section:

- *New Equipment Investigation* is the process of investigating advances in construction equipment technology and determining the implementation costs and maturity of it.
- *New Information Systems Information* is the process of investigating information system advances in construction and determining the implementation costs and maturity of them.
- *New Materials Technology Investigation* is the process of investigating materials advances in construction and determining the implementation costs and maturity of them.

Site Layout Plan

Site Layout Plan is a plan that includes but not limited to a lay down area, tool storage, break areas, and equipment storage to ensure the optimal craft worker productivity. Research projects on site layout plan pointed out the major importance of 5 elements: transportation access, material storage areas, handling spaces for material, administration buildings and welfare facilities. The site layout needs to be dynamic due to the nature of construction project, but as always, the earlier the plan is developed the better. An efficient and proper site layout directly improves labor productivity by preventing crews' interferences (Thomas et al., 1999). The following are the 3 elements of this section:

- *Dynamic Site Layout Plan* is organizing the land on the construction site to allow workers to effectively perform their tasks to complete the project.
- Develop a Site Security Plan is the course of action used by the project team to secure the site.
- Equipment Position Strategy is the plan developed regarding equipment location to perform their designated activities without interfering with other on-site activities.

Category VI – Environmental Safety and Health

Environmental Safety and Health is made up of three sections: Job Safety, Substance Abuse Programs, and Safety Training and Orientation. Below, figure 7 shows the organizational structure of Environmental Safety and Health category.

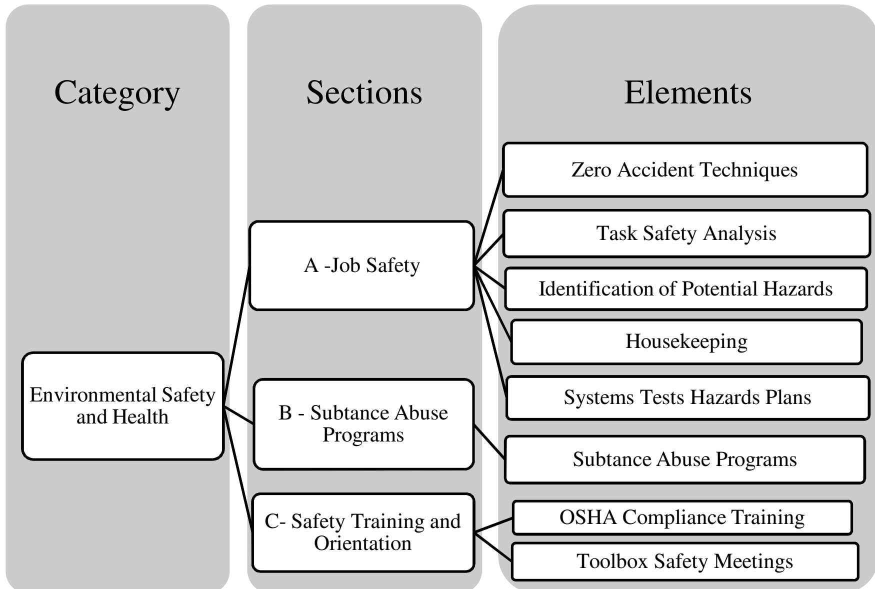

Figure 7 - Organizational Structure of Environmental Safety and Health

Environmental safety and health corresponds to the implementation of practices that ensure the safety and health of craft workers on construction sites. Research shows that the implementation of a formal safety program definitely improves labor productivity. This program reduces incident and injury rates (Hinze and Wilson, 2000). Besides another study conducted by Hinze and Parker pointed out that superintendents that complete project on schedule and under budget were those with the best safety records. Five safety practices proved their efficiency in increasing labor productivity: make safety as a priority during a pre-construction and construction meetings, implementation of safety incentive programs, consideration of safety performance in subcontractors' selection process, performance of pre-employment substance abuse test for employees, and alcohol and drug screening for contractor employees (Hinze and Parker, 1978).

Job Safety

Job Safety is defined as identifying hazards associated with each step of a task and determining how to control the hazards. CII developed practices such as Zero Accident Techniques that should be implemented to ensure workers safety on jobsite. The following are the 5 elements of this section:

- *Zero Accident Techniques* are the identified practices which help reduce injuries and project to achieve the goal of zero accidents.
- *Task Safety Analysis* is the identification of risks and hazards construction tasks created and mitigation strategies to reduce them.
- *Identification of Potential Hazards* is planning for each potential hazard that may result from construction activities.
- *Housekeeping* is the organization and cleaning of the jobsite to reduce debris and hazards.
- *Systems Test hazards Planning* is the development of a plan to address hazardous materials that may appear on-site during construction.

Substance Abuse Programs

Substance Abuse Programs is defined as a program that includes both pre and post-hiring testing for illicit drugs use. CII's report on Zero Accident Techniques research program states "studies show that when random tests for drugs are conducted, better safety performance results" (Hinze, 2003). This section only has one element which is the Substance Abuse Programs itself.

Safety Training Orientation

Safety Training Orientation ensures that all project participants and authorized visitors have the adequate knowledge to protect their health and safety as well as others. Specific practices need to be implemented to ensure the efficiency of safety training orientation. This orientation cover jobsite layout, site-specific safety hazards, location of performed work. Besides more specifically worker should be aware of the hazards and risks of the activities they perform (Hinze and Wilson, 2000). CII's studies show a drop in the recordable incident rates when all workers receive a formal safety training orientation on site and when toolbox safety meeting are hold regularly (Hinze, 2003). The following are the 2 elements of this section:

- *OSHA Compliance Training* is self explanatory.
- *Toolbox Safety Meetings* are regularly scheduled meetings on jobsite with constructor managers and craft workers to discuss risks and hazards of activities currently performed on site.

Level of Planning and Implementation Definition Methodology

Each element description corresponds to a heading, the criteria that are involved in implementing that practice and the definition of each level of implementation for this specific element. The Productivity Practice Index scoring system takes into account the planning and implementation level (PIL). The PIL definitions are element-specific. So, they need to be defined for each element. They are organized from 0 to 5, where 0 corresponds to non-applicable element and 5 to a fully implemented practice. The research team agreed on using this method to evaluate the PIL of the elements to avoid user bias and create more transparency in the scoring system.

For instance, some users may evaluate the PIL high for an element, while other users may rank the same as average or even below average. The research team hopes that using this scoring system will reduce and even eliminate this kind of issues; and make the Productivity Practice Index score even more accurate (Cho, 2000).

Moreover, even if the PIL definitions are element-specific, they are defined to be consistent throughout the tool. This was done by creating a guideline for each PIL. Following are the guidelines that were used to define each level:

Planning and Implementation Level 0: The planning and implementation of the element is not applicable.

Planning and Implementation Level 1: The planning and implementation of the element is not addressed in any capacity on the project.

Planning and Implementation Level 2: The planning and implementation of the element is addressed, but in a below average manner.

Planning and Implementation Level 3: The average level of planning and implementation of the element.

Planning and Implementation Level 4: The planning and implementation of the element is thorough, above average, but not perfect.

Planning and Implementation Level 5: The planning and implementation of the element is at its highest possible (most state of the art and technologically advanced) level.

Each element planning and implementation level is defined using these guidelines. Following is an example of the definitions of the different levels of planning and implementation of the element Project Team Material Status Database, which is located in Category I – Materials Management, Section A: Materials Management Systems:

Planning and Implementation Level 0: Project team material status database is not applicable

Planning and Implementation Level 1: No formal paper based system is used to track material status.

Planning and Implementation Level 2: There is a formal paper based system to track material status.

Planning and Implementation Level 3: A proprietary internal procurement software tool is used but it is not integrated or used by other contractors.

Planning and Implementation Level 4: An available software application is used but it is only integrated internally with your company's project control systems.

Planning and Implementation Level 5: An available software application is used by all contractors that are integrated with your supply chain and other project control systems.

However, for some elements, the definitions of the different PIL were written to prevent each definition from becoming too long. Indeed, when the level of definition of a higher score includes parts from previous level definition, plus additional criteria, the PIL definition contains “Continuation of level X, plus additional criteria”. Below is an example of the PIL definition of the element On-site material tracking technology, which is located in Category I – Materials Management, Section A: Materials Management Systems:

> **Planning and Implementation Level 0:** On-site material tracking technology is not applicable.
>
> **Planning and Implementation Level 1:** No tracking is done on site beyond receivables.
>
> **Planning and Implementation Level 2:** Material is assigned a lay down and storage area and the information is recorded.
>
> **Planning and Implementation Level 3:** Continuation of 2, plus the location information is kept updated in a software system and well defined and followed processes for developing pick lists, flagging, warehouse organization (if applicable) etc. are established.
>
> **Planning and Implementation Level 4:** Continuation of 3, plus the system is supported by tracking software and also supplemented by barcode, GPS, or RFID systems for automated location tracking.
>
> **Planning and Implementation Level 5:** Continuation of 4, plus the tracking system is completely automated and integrated with other project processes.

The PIL description of each element can be found in Appendix B. However, the Productivity Practice Index scoring system was not yet complete. Each element needed to be weighted differently depending on its impact on labor productivity. The weighting process is described in the next chapter.

This chapter recounted the development of the Productivity Practice Index. The index is designed to serve members of construction industry to help select and implement the proper practices to achieve high labor productivity. Chapter 5 exposes the methodology of the elements weighting.

Chapter 5 – Relative Importance of the Index Elements

ORGANIZATION OF THE WEIGHTING PROCESS – SCORE SHEET DEVELOPMENT

Development of the weighting process

The initial framework of the Productivity Practices Index had been developed, but the Productivity Practices Index scoring system was not yet complete. Each element needed to be weighted based on their relative importance in influencing labor productivity. Besides, each section needed to be weighted relatively to other sections, as well as the categories. The Productivity Practices Index scoring system is very similar to systems of other CII tools such as the Project Definition Rating Index (PDRI). Indeed, each Planning and Implementation Level (PIL) for each element represents a different score that simply 0 to 5 thanks to the elements weightings. In addition, the project Productivity Practices Index score is obtained by adding up the different weight of each element rather than the PIL.

The research team members pointed out that all the 53 elements described in the previous chapter were not equally important with respect to their potential impact on craft labor productivity, so a survey was elaborated to attribute weights to the Productivity Practice Index elements. From previous surveys performed by CII, the best way to develop reliable and accurate weights for the Productivity Practices Index was to rely on a broad spectrum of experienced and knowledgeable members of the construction industry (Cho, 2000). Besides, the research team thought that the most appropriate way to conduct that survey was through emails. Participants were asked to rank the importance of each element so that the consensus of survey participants will be used to weight the elements. The results of this survey led to the Productivity Practices Index weighted score sheet.

Several steps were followed in this Productivity Practices Index weighting effort. Surveys were sent to both owners and constructors companies. Then, an analysis was performed and weights were attributed to categories, sections and elements. Finally, a linear interpolation was used to distribute the total weight of the element to the different implementation levels. Figure 8 shows the survey methodology.

Figure 8 - Productivity Practices Index Weighting Methodology

The Productivity Practices Index weighting forms were sent by emails to the research team members asking them to distribute the form to as many co-workers as possible within their companies. Before completing the weighting form, participants could read a brief introduction on the Productivity Practices Index development effort. Then, they had to fill out some demographic background information, which collected information about work experience, industry sectors, locations and other types of information to allow comparisons among experts. Finally, precise instructions were given to survey participants to evaluate the relative importance in respect to craft labor productivity of the categories, sections and elements. They were asked to evaluate the elements based on the definition of the highest level of implementation and planning.

Example of Element Weighting Process

Participants were asked to compare the elements in the same section, the sections in the same category and categories between each others in respect to their positive influence on craft labor productivity. First, they read the definition of the elements/sections/categories. For each group, participants were instructed to assign 1 to the least important element/section/category as the baseline of comparison, 5 to the most important element/section/category, the importance factors 2, 3, or 4 for the others in the group considering their relative importance.

A sample of a valid weighting form of elements of a section used by the research team is shown on Table 2. This is an example of Section A Materials Management Systems of Category I Materials Management, one of the 18 index sections. The expert who filled out this weighting form thought that among the 4 elements of this section, the procurement plan for materials and equipment had the most significant positive impact on craft labor productivity and project team material status database had the least positive impact. On-site material tracking technology and material delivery schedule were both more important than project team material status database but not as much as the procurement plan for materials and equipment.

	A. Materials Management Systems	**Importance Factor**
Group 3	**1. Project team material status database**	1
	2. On-site material tracking technology	3
	3. Material delivery schedule	4
	4. Procurement plan for materials and equipment	5

Table 2 - An example of weighting Materials Management System Section

Another sample of the weighting form of sections of a category used by the research team is shown on Table 3. This is an example of category IV Human Resource

Management, one of the 6 index categories. Thus, the participant felt that among the 4 sections of this category, Behavior had the most significant impact on craft labor productivity, Organizational Structure the least positive influence on construction productivity and Training and Development and Employment had a relative equivalent impact on on-site productivity but lower than Behavior and higher than Organizational Structure.

Group 11	IV - HUMAN RESOURCE MANAGEMENT	Importance Factor
	A. Training and Development	3
	B. Behavior	5
	C. Organizational Structure	1
	D. Employment	3

Table 3 - An example of Weighting Human Resource Management Category

Summary of the Weighting Methodology

In theory, the highest level the practice (element) is implemented, the better the craft labor productivity. Thus, if the practice is fully planned/implemented it should be represented by a high score thanks to its highly positive impact on craft labor productivity. Conversely, if the practice is poorly or not planned/implemented, it should be represented by a very low score such as 1. Besides, in some case scenarios, some elements/practices are non-applicable due to some unique characteristics of construction projects. The importance factors that participants assigned represent the relative importance of the positive impact on craft labor productivity. The higher the importance factor assigned to an/a element/section/category, the more important the element/section/category is in respect to the positive impact on craft labor productivity compare to the other elements/sections/categories.

The Productivity Practices Index weighting forms were collected along with the background information to perform further analysis and assign scores to elements, sections and categories.

WEIGHTING SURVEY

Participants

All survey participants were asked to fill out the demographic information which asks information about the number of years of experience within the construction industry, the location, the industry sector, the type of organizations, and other useful information, included in the Productivity Practices Index weighting form file. A blank copy of this questionnaire is available in Appendix C.

The survey was sent out to organizations represented in RT 252. By the end of 2009, a total of 103 Productivity Practice Index weighting forms were collected from over 9 companies (the list of the companies is located in Appendix D). Among these 103 forms, 73 were from contractor organizations and 30 from owner organizations. The involvement of both owners and contractors was a very important point for the research team to obtain unbiased inputs for different perspectives. Figure 9 summarizes the number of Productivity Practice Index weighting effort participants, the type of organization they represent, and their level of experience. Obviously, it's not a perfect distribution between owners and contractor but both sides are represented.

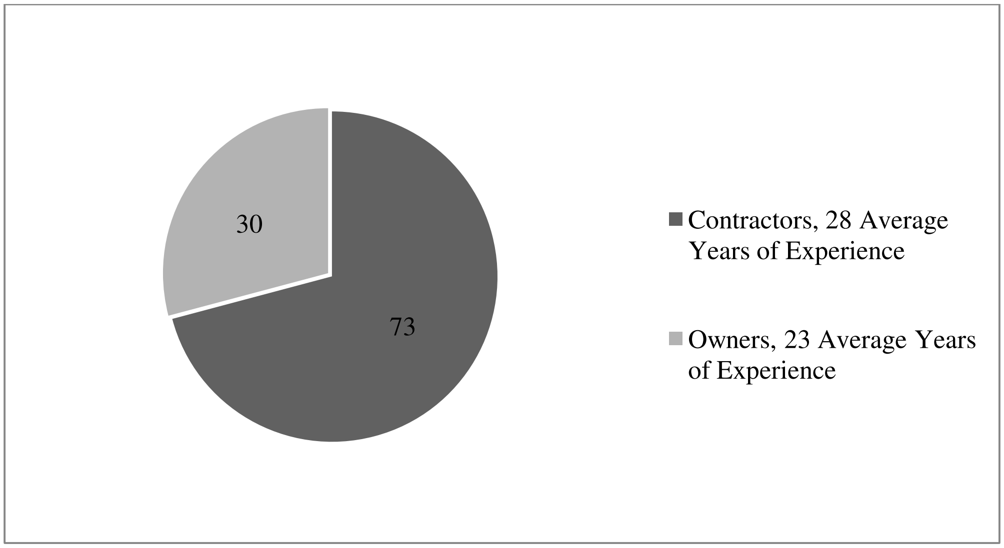

Figure 9 – Productivity Practices Index Weighting Survey Demography

Following, figure 10 represents the distribution of members experience by projects types; the dominant number of heavy industrial construction projects is obvious. Besides, the total number of project is higher than the number of forms because the choice was not exclusive.

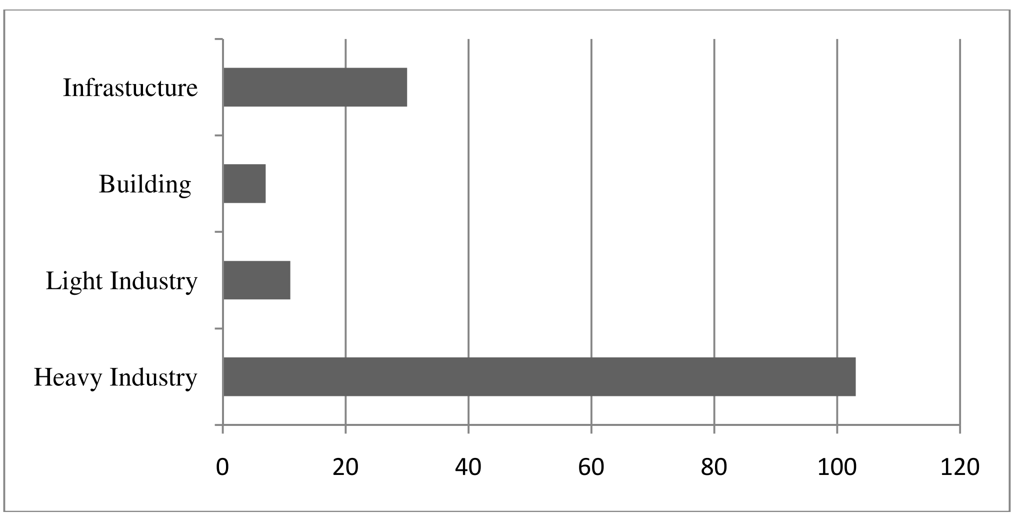

Figure 10 - Productivity Practices Index Weighting Survey Industry Sectors

Weighting Survey Package

The researchers prepared an excel file and a form for the participants. The Productivity Practices Index Weighting form and demographic information sheet were completed by the participants and sent back to the research team. Some other information, such as a brief overview of the Productivity Practices Index, the instructions on how to fill out the weighting form and the definition of each individual element, section and category were also included in the excel file. A copy of the Productivity Practice Index weighting survey package is available in the Appendix C.

ANALYZE OF SURVEY OUTCOMES

The research team received 113 forms. But, before the development of the weights to the Productivity Practices Index elements, sections and categories, 10 of the 113 received forms were removed because they were invalid. Some forms used other numbers than 1, 2, 3, 4, and 5 (see figure 11), other forms were incomplete (see figure 12).

	B. Work Face Planning	Importance Factor
Group 9	1. Well defined scope of work	1
	2. Utilization of software to assist in generating work packages	7
	3. Project model requirements	6
	4. Dedicated Planner	3
	5. Identify required permitting	5
	6. Engineering Work Packages (EWP)	4
	7. Construction Work Packages (CWP)	8
	8. Field Installation Work Packages (FIWP)	2

Figure 11 – Example of an invalid form due to invalid numbers

	B. Work Face Planning	Importance Factor
Group 9	1. Well defined scope of work	
	2. Utilization of software to assist in generating work packages	1
	3. Project model requirements	
	4. Dedicated Planner	2
	5. Identify required permitting	
	6. Engineering Work Packages (EWP)	3
	7. Construction Work Packages (CWP)	5
	8. Field Installation Work Packages (FIWP)	4

Figure 12 – Example of an invalid form because it is incomplete

Therefore, 103 forms were used to develop the Productivity Practices Index elements, sections and categories weights.

Several steps were followed in the development of the Productivity Practices Index score sheet. Each weighted form was copied into a unique Microsoft Excel 2007 sheet. The first step consisted in calculating the average importance factor of each element, section and category of companies that participated in the survey and the average importance factor of the ones of the research team. The research team wanted to warrant the consistency of the result.

DEVELOPMENT OF THE ELEMENTS, SECTIONS AND CATEGORIES WEIGHTS

This section describes the calculation of the weight of elements, sections and categories. From the unique Microsoft Excel sheet developed with all the data of the valid forms, the average important factor of each category, section, and element were calculated. Figure 13 shows the average important factor of category I – Materials Management.

Group 2	I - MATERIALS MANAGEMENT	Importance Factor
	A. Materials Management Systems	3.7
	B. Receipt and Inspection of Materials	3.1

Figure 13 - Important Factors of Sections of Materials Management Category

Once all the averages were calculated from the 103 valid forms, the maximum score of the 53 elements, 18 sections and 6 categories were determined. The research team defined that the maximum Productivity Practices Index score attainable to be 2000, which represents the best case scenario, the best level of practice implementation. The lowest score is theoretically zero where all the elements are non-applicable, which usually doesn't match the reality.

For example, to obtain the maximum score of Category I – Materials Management, the importance factor of this category was divided by the total of all the importance factors of the 6 categories times the maximum score 2000. Likewise, to obtain the maximum score of Section A, the importance factor of this section was divided by the total of all the importance factors of the sections of this category times the maximum score of the category. And to obtain the maximum score of Element X, the importance factor of this element was divided by the total of all the importance factors of the elements of this section times the maximum score of the section. All the weights of categories, sections and elements are located in Appendix E. Below, table 4 shows the maximum scores of the categories.

CATEGORIES	MAXIMUM SCORE
Materials Management	357
Equipment Logistics	293
Craft Information Systems	295
Human Management Behavior	283
Construction Methods	278
Environmental Safety and Health	394

Table 4 - Maximum Scores of the Productivity Practices Index Categories

All the elements that are non-applicable (N/A) to the construction project for whatever reason, were given the score zero, the first levels of planning and implementation were given the score 1 for all the elements (Te, 2009). To determine the score of the other PIL, the score of PIL 1 and 5 were linearly interpolating using the following formulas:

PIL 2 Score = (PIL 5 Score – 1)/4 + 1

PIL 3 Score = (PIL 5 Score – 1)/4 + PIL 2 Score

PIL 4 Score = (PIL 5 Score – 1)/4 + PIL 3 Score

Then, each PIL Score was rounded to the closest integer. Due the scores rounded, the total of the categories scores is 1999 instead of 2000. The results of the interpolation process, so the PIL scores of all the elements, are summarized in the Productivity Practices Index score sheet in appendix F. Below, Table 5 shows the distribution of the PIL Score for the elements of Materials Management Systems section.

I - MATERIALS MANAGEMENT							
Section							Score
Element	0	1	2	3	4	5	
A. Materials Management Systems							
1. Project team material status database	0	1	10	19	28	36	
2. On-site material tracking technology	0	1	12	23	34	45	
3. Material delivery schedule	0	1	15	29	43	59	
4. Procurement plan for materials and equipment	0	1	15	29	43	56	
Total Maximum Score of Material Management Systems Section						**196**	

Table 5 - Distribution of PIL Score of the Elements of Materials Management Systems

The element has the higher score when it reaches the PIL 5, which represents the best case scenario. However, some projects may not need or want to reach this level of implementation and planning.

RESULTS

Categories were ranked in order of importance in respect to their perceived positive impacts on craft labor productivity. A higher score means a potential more significant impact on construction productivity. Table 6 shows the categories' weights in order of importance.

CATEGORIES	Weights
VI – Environmental Safety and Health	394
V – Construction Methods	378
I – Materials Management	357
III – Craft Information Systems	295
II – Equipment Logistics	293
IV – Human Resources Management	282

Table 6- Productivity Practices Index Categories Weights

Categories' weights are not so different; they are fairly even, so all the categories play a significant role in improving craft labor productivity. The most important category is the one related to safety and health which represents the current trends and focus in the construction industry, likewise construction methods such as pre-fabrication and modularization. However, either sections or elements of different categories and sections can't be compared due to the fact that the number of sections in each category is different. Likewise, the number of element in each section and category is different. Thus, the score of each element doesn't represent the importance of this element related to all the elements, but the importance of this element related to the other elements of the same section.

A high Productivity Practice Index score corresponds to a very high level of implementation of well-known practices for improving construction productivity. Conversely, a low Productivity Practice Index score represents a poor implementation of practices that have significant impact on craft labor productivity.

If all the elements PIL are one, two, three, four or five, the Productivity Practices Index score would be respectively, 53, 536, 1030, 1492 and 2000. At the beginning of the construction phase, the project may be close to 536 but the more advances the project, the higher the score should be. 2000 may never be reached by a project but it might not be the objective. Indeed a score of 1800 can be sufficient for some construction projects.

Chapter 6 – Testing the Index

ORGANIZATION OF THE TEST PROCESS

Purpose of the survey

The initial framework of the index had been developed, the index scoring system was complete, but the index still had to be tested on construction projects. Indeed, despite the fact that the 53 developed elements were identified and weighted based on the knowledge and experience of both owners and contractors, the Productivity Practices Index still had to be tested. So, an index testing survey package was developed to perform preliminary tests and analyses of the developed index. The main purpose of the testing effort was to look at the relationships between craft productivity data such as electrical and piping productivity measurements by the Benchmarking and Metrics CII program and Productivity Practices Index scores.

This testing effort was conducted through email surveys using a questionnaire developed by the research team on completed projects. The construction projects involved in this validation effort were projects that submitted data to the CII Benchmarking and Metrics program 2009. This survey focused on gathering Productivity Practices Index project scores and electrical and piping productivity data.

Participants

The CII database was considered a reliable source for the Productivity Practices Index testing process. In order to have the most unbiased sample of construction projects and reliable craft productivity data, the research team decided to send the surveys, with CII agreement, to construction projects that submitted data in 2009 to the Benchmarking and Metrics program. So, the research team worked in collaboration with CII Benchmarking and Metrics (BM&M) group. These projects submitted their craft productivity data such as electrical and piping productivity using measurement methods developed by previous CII research programs.

The surveys were sent to 29 construction projects on March, 26th 2010. By June, 11 projects had sent back the completed project score sheets, which represents a 38% response rate. All these projects were of the heavy industrial type but diversity was found in the projects subcategories, projects natures and contract types. Among this 11 construction projects, 5 were submitted by contractors and 6 by owners. Following, figure 14 shows the distribution of projects subcategories and figure 15 shows the split between the different project natures.

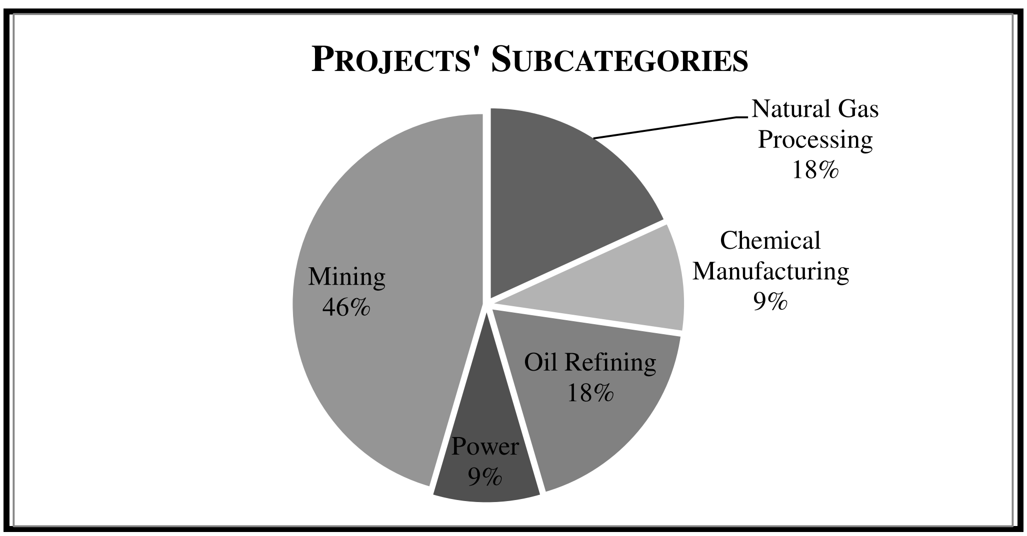

Figure 14 - Testing Survey CII BM&M Participants – Projects Subcategories

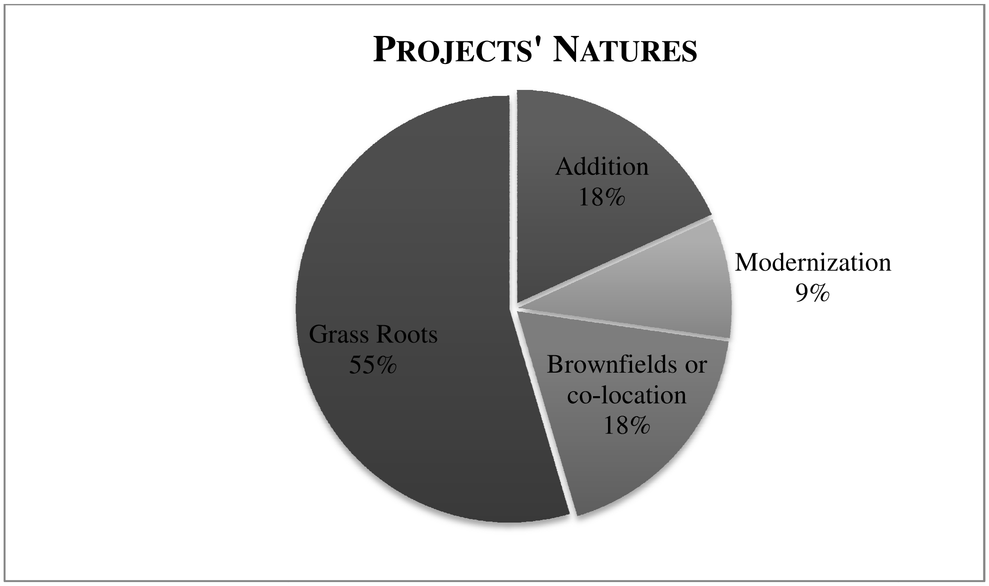

Figure 15 - Testing Survey CII BM&M Participants - Project Nature

Before starting the analysis of the results, a screening of all projects that returned questionnaires was performed. Only 5 projects out of the 11 submitted electrical productivity data and only 4 projects out of the 11 submitted piping productivity data; so 5 projects were discarded but will be used in future testing efforts.

Index Testing Survey Package

To test the viability of the index, a survey package was developed. For a more efficient communication, the survey package was color coded. The whole survey package is located in Appendix G, but the different documents of the package are briefly described in the following part:

- *A cover letter* addressed to the BM&M associate or the project manager. It provides an overview of the research program, the validation effort, and the next steps of the research process. It introduces the purpose of the different color coded documents enclosed in the survey package. It also explains the reasons of why the research team is asking them to participate in this testing effort.

- *The Productivity Practices Index Introduction.* This document was divided into four main sections. The first was a brief introduction on the index, the purpose and scope of the research. The second part exposed the potential benefits of this index. Then, the third part explained the methodology followed to develop this index and last part introduced the expected products of the research program. This document was printed on a blue sheet.
- *The Testing Questionnaire of the Index.* It was a 6-page document. It provided instructions for rating a project, giving an example on how to assess an element. It included an Unweighted Index Score Sheet to evaluate the levels of planning and implementation of all the Index elements of the participant's project. At the end of this document, how much time the participants spent to fill out that form, was asked. This document was printed on a white sheet as the cover letter.
- *The Productivity Practices Index Elements Descriptions.* A copy of the Index elements description was included in the survey package to help the participant to accurately assess the level of implementation and planning of each element during the evaluating process. This document was printed on a yellow
- *Self Addressed and Stamped Envelope.* The enveloped was provided to encourage and facilitate the participant to send back the questionnaire.

ANALYSIS OF THE SURVEY RESULTS

The mail survey gathered data on the evaluation of construction projects using the unweighted version of the Productivity Practices Index project score sheet. The projects' craft productivity data and projects' background information were provided by the CII BM&M group.

Project Rating Information

The first purpose of the testing process was to explore the relationships between Productivity Practices Index scores with the projects craft productivity levels. The research team decided to use the unweighted index score sheet to prevent participants from being influenced by the scores and so having a biased assessment of the 53 elements. The participants were asked to evaluate how well the elements were implemented across the duration of the construction phase of the project. Participants were asked to draw only one check (√) in the box corresponding to the appropriate level of implementation and planning on a scale ranging from 0 to 5 using the elements descriptions document. The author of this thesis calculated the corresponding index projects scores.

The assigned level of planning and implementation of each element was associated to a different score depending on each element. The scores were entered in the Excel weighted project score sheet in the score column. As shown in figure 16, the boxes corresponding to the planning and implementation level turned gray in the project score sheet.

IV - HUMAN RESOURCE MANAGEMENT							
Section							Score
Element	0	1	2	3	4	5	
A. Training and Development							51
1. Trades technical training	0	1	12	23	34	47	34
2. Career development	0	1	9	17	25	33	17
Total Maximum Score of Training and Development Section						80	
B. Behavior							37
1. Recognition Programs	0	1	7	13	19	24	24
2. Financial Incentive Programs	0	1	8	15	22	28	8
3. Social Activities	0	1	5	9	13	16	5
Total Maximum Score of Behavior Section						68	
C. Organizational Structure							61
1. Maintain Stability of Organization Structure	0	1	9	17	25	32	25
2. Clear Delegation of Responsibility	0	1	10	19	28	36	36
Total Maximum Score of Organizational Structure Section						68	
D. Employment							44
1. Retention Plan For Experienced Personnel	0	1	12	23	34	46	23
2. Exit Interview	0	1	6	11	16	21	21
Total Maximum Score of Employment Section						67	
Overall Human Resource Management Score :							193

Figure 16 - Example of a Completed Project Score Sheet

Once all elements scores were attributed, they were added to obtain sections, categories and overall index project score. Then, the maximum index score attainable for this project was calculated. To evaluate this score, all the maximum score of the elements with an implementation level of zero were added, and the total was subtracted to the maximum index score (2000 points). Finally the project score was divided by the maximum attainable project score to obtain the %Index score. The index scores for the 6 projects ranged from 56.36% to 78.00%.

Project Scores Analysis

Once all the project scores calculations were done, it was observed that one of the projects had a overall score of 1496 out of a 1918 maximum attainable score (i.e. 78.00% Index Score). It should be remembered that if all Productivity Practices Index elements had the implementation levels of 5, the project's total Index score would be 2000 points (i.e. 100%), if all had implementation levels of 4 the Index score would be 1492 points (i.e. 74.6%). Thus, this project almost scored the perfect score and the most reasonable score in practice.

Table 7 presents a summary of Productivity Practices Index scores for the sample projects and their categories scores. The first column corresponds to the project identification number given by CII to respect the confidentiality clauses. The other columns represent the project score, the maximum score and the Index % score. The other groups of three columns are actual score, maximum attainable scores and percentages of six categories in the Productivity Practices Index.

	Project		
Project	Score	Max	%
O9258	1176	1872	62.82%
O8496	1462	1872	78.10%
C8876	1100	1445	76.12%
C8508	1503	2000	75.15%
C8317	1257	2000	62.85%
C8276	1116	1980	56.36%

	Category I			Category II			Category III		
Project	Score	Max	%	Score	Max	%	Score	Max	%
O9258	246	311	79.10%	205	293	69.97%	107	255	41.96%
O8496	264	311	84.89%	225	293	76.79%	211	255	82.75%
C8876	238	311	76.53%	0	0	100.00%	174	271	64.21%
C8508	322	357	90.20%	148	293	50.51%	203	295	68.81%
C8317	220	357	61.62%	112	293	38.23%	162	295	54.92%
C8276	158	357	44.26%	110	293	37.54%	135	295	45.76%

	Category IV			Category V			Category VI		
Project	Score	Max	%	Score	Max	%	Score	Max	%
O9258	173	283	61.13%	191	335	57.01%	254	395	64.30%
O8496	254	283	89.75%	213	335	63.58%	295	395	74.68%
C8876	51	89	57.30%	247	379	65.17%	390	395	98.73%
C8508	170	283	60.07%	312	379	82.32%	348	395	88.10%
C8317	121	283	42.76%	261	379	68.87%	381	395	96.46%
C8276	130	283	45.94%	204	359	56.82%	379	395	95.95%

Table 7 - Index Scores of Sample Projects

The higher the score, the most planned and implemented the project the more desirable the craft productivity. Conversely, the lower the score the less planned and implemented the project and the less desirable results.

BM&M Projects Characteristic Analysis

The BM&M program collected a lot of information on projects, such as industrial sectors, sector subcategories, contract types, project nature, project delivery methods, project complexity, project scope and other that the research team didn't use to conduct this analysis. Besides, BM&M collected productivity data at different levels. To perform this analysis, the team focused on the two first higher levels of BM&M. The first level is the total electrical and piping productivity. The second level is illustrated in figure 5, below.

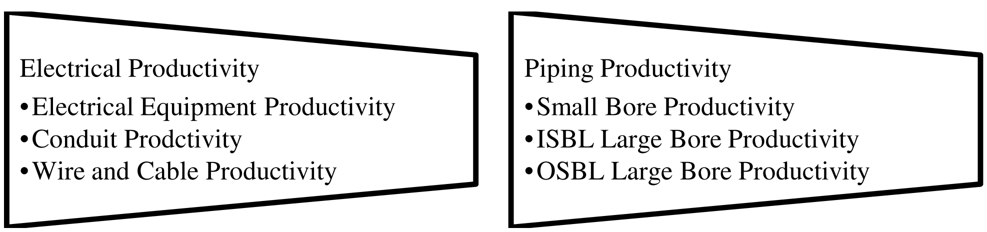

Figure 17 - Crafts Productivity Metrics

Analyzing project craft productivity and its relationship with planning and implementation levels of management practices would lead to a better interpretation of the Index scores of a construction project. This analysis will be effective when a significant amount of BM&M construction projects have been scoring themselves with the Productivity Practices Index during the construction phase.

Analysis of BM&M Projects Performance

In this part, collected data on project trades productivity are reported and discussed to give more detailed about the projects involved in the Productivity Practices Index testing process. Data on two main trades were exploited; they are electricity and piping. Quantities and durations were collected to calculate the productivity of each activity.

Electrical Productivity

The ratio between the work hours and the quantities installed represents the productivity. To recap, the lower number is the better. Electrical productivity data are presented in Table 8. The electrical quantities are in linear feet, work hours in hours and so the productivity is in hours per linear foot. The best steel productivity is 0.05 and the worse is 0.39. The average electrical productivity is 0.19, which represents a typical electrical productivity value.

	Conduit			**Wire and Cable**			**Total Electrical**		
Project ID	**Quantities**	**work Hours**	**Productivity**	**Quantities**	**work Hours**	**Productivity**	**Quantities**	**work Hours**	**Productivity**
C8276	11495	4439	0.39				11495	4439	0.39
C8317	182991	30745	0.17	666444	15964	0.02	849435	46709	0.05
C8508	138730	46070	0.33	1089795	60210	0.06	1228525	106280	0.09
C8876	40299	25156	0.62	161968	33549	0.21	202267	58705	0.29
O8496	157581	55374	0.35	534833	37288	0.07	692414	92662	0.13

Table 8 - Electrical Productivity data of Sample Projects

Piping Productivity

Then, the piping trade was studied as craft productivity. Table 9 presents the piping productivity data submitted by a few projects. As can be seen in Table five, only four projects submitted some data about piping trades. The piping quantities are in linear feet, work hours in hours and so the productivity is in hours per linear foot. The best piping productivity is 2.72 and the worse is 4.53.

	Small Bore			ISBL Large Bore		
Project ID	**Quantities**	**work Hours**	**Productivity**	**Quantities**	**work Hours**	**Productivity**
C8317	171399	486438	2.84	119979	340506	2.84
C8508	192019	1020470	5.31	1510676	3618010	2.39
C8876	34288	67686	1.97	22967	61533	2.68
O9258	39000	50000	1.28	30000	153000	5.10
	OSBL Large Bore			**Total Piping**		
Project ID	**Quantities**	**work Hours**	**Productivity**	**Quantities**	**work Hours**	**Productivity**
C8317	51420	145931	2.84	342798	972875	2.84
C8508	0	0		1702695	4638480	2.72
C8876	161500	582387	3.61	218755	711606	3.25
O9258	10000	155000	15.50	79000	358000	4.53

Table 9 - Piping Productivity Data of Sample Projects

Analysis of the influences of the Index on the trades' productivity

The project Productivity Practices Index scores versus the trades' productivity data were plotted. An analysis was performed on all those plots to identify the trends. To recap, a high Index score should correspond to a good productivity, i.e. a low number.

Figure 18 shows the plots of the Index overall projects scores and electrical productivity, while figure 19 illustrates the plots of the Index overall projects scores and piping productivity for each project.

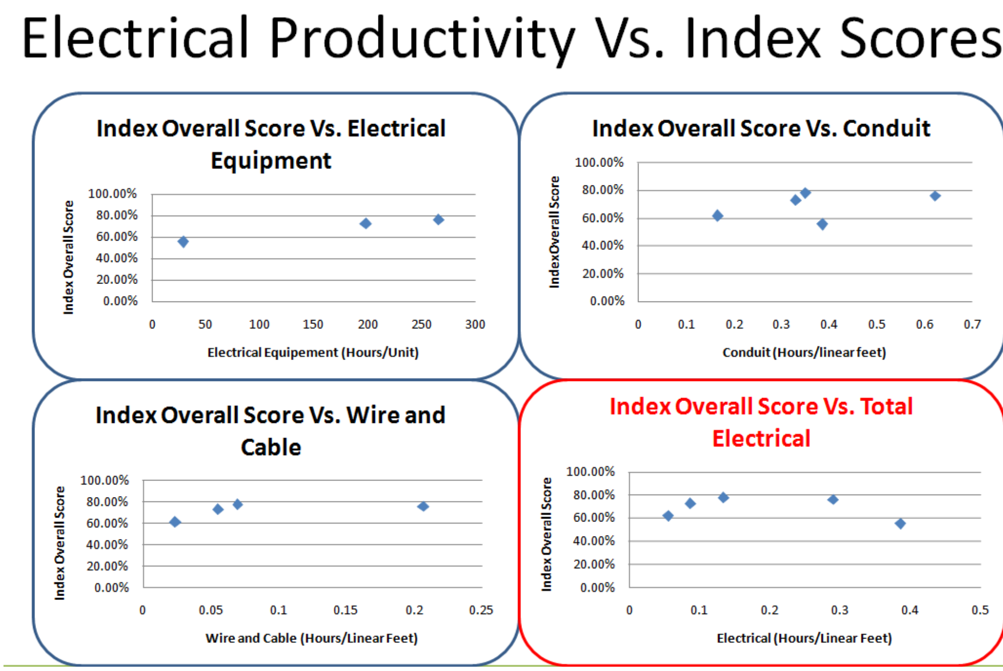

Figure 18 Index Overall Score versus Electrical Productivity

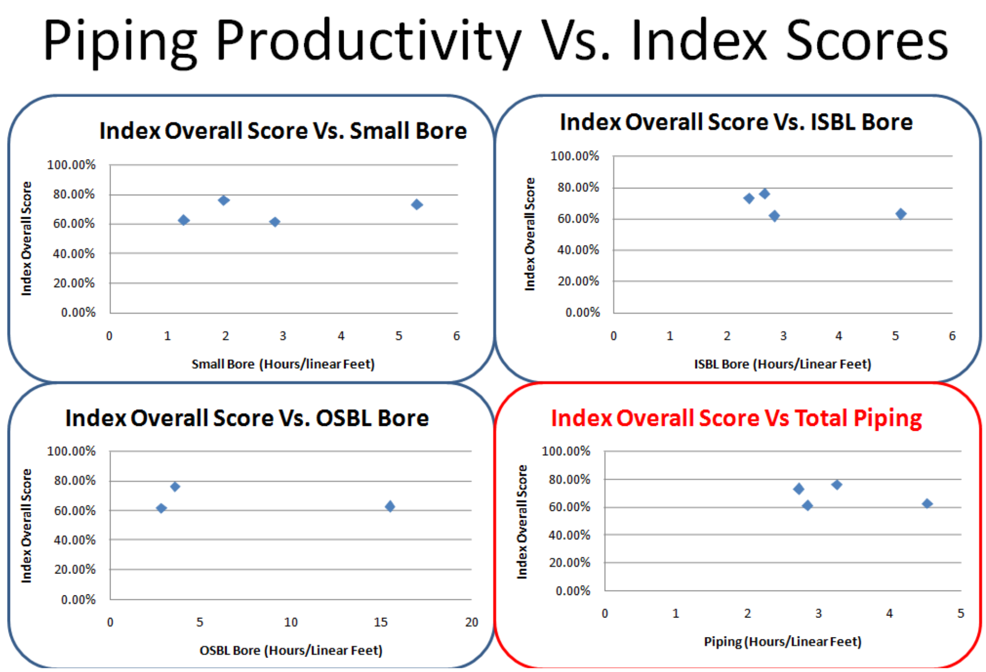

Figure 19 -Index Overall Score versus Piping Productivity

Index Overall Scores

All the sample projects Index overall scores were calculated and compared to all the craft productivity data available. Table 10 shows the Productivity Practices Index scores and the two main craft productivity areas which are electrical and piping. Piping productivity and electrical productivity show encouraging trends, i.e. a high Index score corresponds to a low productivity number which is a good productivity. Conversely, a low Index score corresponds to a big productivity number or a bad productivity.

Project ID	**BPPII %**	**Electrical Productivity (Hrs/LF)**	**Piping Productivity (Hrs/LF)**
C8276	56.36%	0.39	
C8317	62.85%	0.05	2.84
C8508	75.15%	0.09	2.72
C8876	76.06%	0.29	3.25
O8496	78.00%	0.13	
O9258	62.83%		4.53

Table 10 - Index Scores and Craft Productivity Data of CII Projects

Materials Management

Materials Management is the first Index category. The influence of Material Management practices on the different trades' productivity can be observed in Table 11. Electrical productivity versus the Material Management scores shows encouraging trends. Indeed, the worse electrical productivity which is 0.39 Hours/Linear Foot corresponds to the worse Materials Management Score, 44.26%. Conversely the second best electrical productivity, 0.09 Hours/Linear Foot, corresponds to the best Material Management score, i.e. 90.20%. However, such trends are not observed piping productivity.

Project ID	Material Management %	Electrical Productivity (Hrs/LF)	Piping Productivity (Hrs/LF)
C8276	44.26%	0.39	
C8317	61.62%	0.05	2.84
C8508	90.20%	0.09	2.72
C8876	76.19%	0.29	3.25
O8496	83.47%	0.13	
O9258	77.03%		4.53

Table 11 - Materials Management Scores and Craft Productivity Data

Equipment Logistics

Equipment Logistics is the second Productivity Practices Index category. Table 12 presents the influence of Equipment Logistics practices implementation on the different trades' productivity. Not any significant trends can be observed for this category, so, more data need to be collected to conclude on the potential influence of this category. Besides, a deeper analysis pointed out that some second level productivity data such as pipe racks and utility bridges show encouraging trends with Equipment Logistics.

Project ID	Equipment Logistic %	Electrical Productivity (Hrs/LF)	Piping Productivity (Hrs/LF)
C8276	37.54%	0.39	
C8317	38.23%	0.05	2.84
C8508	50.51%	0.09	2.72
C8876	0.00%	0.29	3.25
O8496	76.79%	0.13	
O9258	69.97%		4.53

Table 12 - Equipment Logistics Scores and Craft Productivity Data

Craft Information Systems

The third Productivity Practices Index category is Craft Information Systems. The impact of Craft Information Systems practices on the craft productivity is exposed in Table 13. Electrical and piping productivity performances versus the Craft Information Systems scores show encouraging trends. Indeed, the worse piping productivity which is 4.53 Hours/Linear Foot corresponds to the worse Craft Information Systems Score, 41.96%. Conversely the best piping productivity, 2.72 Hours/Linear Foot, corresponds to the best Craft Information Systems score, i.e. 68.81%.

Project ID	Craft Information Systems %	Electrical Productivity (Hrs/LF)	Piping Productivity (Hrs/LF)
C8276	45.76%	0.39	
C8317	54.92%	0.05	2.84
C8508	68.81%	0.09	2.72
C8876	64.21%	0.29	3.25
O8496	82.75%	0.13	
O9258	41.96%		4.53

Table 13 - Craft Information Systems Scores and Craft Productivity Data

Human Resources Management

Human Resource Management is the fourth Productivity Practices Index Category. The influence of the effective implementation of Human Resource Management techniques on craft productivity is presented in Table 14. Encouraging trends can be observed between electrical productivity and Human Resources Management. However, such trends are not observed for piping productivity. Inverse trends were pointed out for piping productivity. Indeed, the best productivity received the worse Human Resource Management score.

Project ID	Human Resource Management %	Electrical Productivity (Hrs/LF)	Piping Productivity (Hrs/LF)
C8276	45.94%	0.39	
C8317	42.76%	0.05	2.84
C8508	60.07%	0.09	2.72
C8876	57.30%	0.29	3.25
O8496	89.75%	0.13	
O9258	61.13%		4.53

Table 14 - Human Resources Management Scores and Craft Productivity Data

Construction Methods

The fifth Productivity Practices Index category is Construction Methods. An analysis on the potential effect of the implementation of best practices related to Construction Methods was conducted and the results are presented in Table 15. Both electrical and piping productivity performances versus the Construction Methods scores show encouraging trends. Indeed, the worse piping productivity which is 4.53 Hours/Linear Foot corresponds to the worse Construction Methods Score, 57.01%. Conversely the best piping productivity, 2.72 Hours/Linear Foot, corresponds to the best Construction Methods score, i.e. 82.32%.

Project ID	Construction Method %	Electrical Productivity (Hrs/LF)	Piping Productivity (Hrs/LF)
C8276	56.82%	0.39	
C8317	68.87%	0.05	2.84
C8508	82.32%	0.09	2.72
C8876	65.17%	0.29	3.25
O8496	63.58%	0.13	
O9258	57.01%		4.53

Table 15 - Construction Methods Scores and Craft Productivity Data

Environmental Safety and Health

Environmental Safety and Health is the most important in terms of weight. Results of the data collected on craft productivity and the Environmental Safety and Health are exposed in Table 16. Encouraging trends are observed between piping productivity and Environmental Safety and Health scores. Indeed, the worse piping productivity which is 4.53 Hours/Linear Foot corresponds to the worse Environmental Safety and Health Score, 64.03%. Conversely one of the best piping productivity, 2.84 Hours/Linear Foot, corresponds to the second best Environmental Safety and Health score, i.e. 96.46%. However, such trends are absent for electrical productivity.

Project ID	Environmental Safety and Health %	Electrical Productivity (Hrs/LF)	Piping Productivity (Hrs/LF)
C8276	95.95%	0.39	
C8317	96.46%	0.05	2.84
C8508	88.10%	0.09	2.72
C8876	98.73%	0.29	3.25
O8496	74.68%	0.13	
O9258	64.30%		4.53

Table 16 - Environmental Safety and Health Scores and Craft Productivity Data

SUMMARY

The possibility of calculating a score for each Productivity Practices Index category, allows he index user to identify the project weak areas. Indeed, it could help project management team to be aware of the categories that need improvement. Moreover, the index allows management teams to select and efficiently implement the appropriate practices to effectively meet the proper levels of planning and implementation of the index elements.

The initial observed trends between projects craft productivity and projects Productivity Practices Index scores allow for further and deeper analyses of a project index score. These trends are encouraging and confirm the potential of the Productivity Practices Index as a reliable indicator of project craft productivity performances. These preliminary tests and analyses helped the research team to understand the potential utilization of the index in a real construction project environment. However, the amount of data collected is not enough to perform a meaningful analysis of the correlation between project index scores and crafts productivity. Indeed, even if the results of the preliminary tests were highly encouraging; due to the small size of the projects sample involved in this initial index testing process, no generalization can be drawn from these results. Hence, more projects index scores and craft productivity data need to be gathered to perform a quantitative analysis of the correlation between index scores and craft productivity performances in order to completely validate the index as a reliable indicator of project craft productivity performance.

Chapter 7 – Conclusions and Recommendations

The Productivity Practices Index has been developed to help project managers and superintendents to identify weak areas that need actions to be taken to improve them by implementing the appropriate productivity practices. This index, if properly used, can effectively help to improve craft productivity on a construction site. It includes six major management areas: Materials Management, Equipment Logistics, Craft Information Systems, Human Resources Management, Construction Methods and Environmental Health and Safety. In developing the Productivity Practices Index, relevant literature and experts' knowledge and experience were taken into account. The index was preliminary tested by potential future users.

REVIEW OF THE RESEARCH OBJECTIVES

As stated in Chapter 1, this research project had four main objectives; how each of them was met by the research team is discussed as follows:

- **Objective 1: Identify initiatives, techniques, or practices that have a significant positive relationship with craft productivity.** Practices, techniques and initiatives affecting craft productivity were identified using two principal resources: an extensive literature review and the knowledge and experience of the research team members. From this effort of Productivity Practices Index development, fifty three practices were identified, defined and grouped into six categories and eighteen sections.
- **Objective 2: Develop a checklist that project team can use for determining the productivity practices that need to be implemented**

before introducing an innovation. The Productivity Practices Index was developed as a metric and a method to improve craft productivity by implementing best management practices. Five levels of planning and implementation were specifically defined for each element and are included in the Elements Descriptions document used by index users during the evaluation process. Thus the evaluation of each element is more rational, less subjective and unbiased. Besides, the index user can identify weak management areas that need attention.

- **Objective 3: Prioritize the identified practices according to their potential impact on craft productivity.** The identified Productivity Practices Index elements were weighted base on their relative importance and positive impact in respect to the project craft productivity. The weighting process was rigorous and involved 103 participants, both owners and contractors, with 28 average years of experience and the research team composed of both experienced industry and academic experts. Analyses performed on the inputs pointed out many similarities between experts viewpoints on effective management practices that were shared throughout the construction industry. This fact confirms the reliability of the Productivity Practices Index elements weights. The elements weights obtained from the weighting process were combined to create the final weighted index called the Productivity Practices Index Score Sheet.
- **Objective 4: Perform preliminary tests and analyses of the developed index.** The testing effort was conducted and some analyses were performed to explore the relationships between electrical and piping productivity performances and the Productivity Practices Index scores. The index was

tested on 6 different projects using the project score sheet. The Index scores were calculated for each project and piping and electrical productivity data were collected.

LIMITATIONS

The most important limitations include the following:

- The current very small sample size prevents the research team to validate the index. More data need to be collected and the index should be tested on more diverse projects. Besides, larger samples can bring different results. The index was tested only on a few heavy industrial projects. Thus it is difficult to generalize the results to the entire construction industry.
- In the weighting process, the weights of implementation and planning levels 2, 3 and 4 were calculating using linear interpolation formula. Thus, if a project A reached implementation level 2 for an element X and goes to implementation level 3 by adding resources, this project will gain as many point as a project B which is level 3 on this element and adds resource to reach level 4. However the amount of resources to go from level 2 to 3 is more important than the amount to go from level 3 to 4, and the number of points gained is the same. The index doesn't take into account how much effort is required to go from one level to another.
- The analyses for the testing process took into account only two craft productivity data: electrical and piping trades' productivity performances. The research team decided to focus on these two trades because they are the two main activities on industrial construction projects.

- The research team pointed out that no meaningful quantitative interpretation of the Productivity Practices Index scores was possible due to the small number of construction projects on which the Index was tested.
- The process of collecting Productivity Practices Index scores was based on volunteering so the sample might not be representative of the whole construction industry.

CONTRIBUTIONS

This research makes important contributions to the body of knowledge, more specifically in the area of craft productivity and management practices. Previous research supported by CII had identified factors and management practices that affected craft productivity. This research program took lots of their outcomes to build a useful index. The main contributions are discussed below:

- The identification of the most important management practices that affect craft productivity: the checklist of 53 elements that help project managers and superintendents to effectively deal with craft productivity issues.
- The determination of the relative importance of the Productivity Practices Index elements: the Productivity Practices Index elements weights development process using over 100 experts inputs highlighting the most important practices that must be implemented to have a successful project.

RECOMMENDATIONS

The Productivity Practices Index as developed and tested in this master thesis could be used for identifying, assessing and monitoring weak management areas that need attention and improvements. This research has been sponsored by CII and most of the data collections were done on projects of CII members companies. For the weighting process, data collection was involving people from both all around the United States and Brazil in all industry sectors, and the definitions of elements are pretty generic. However, the heavy industrial construction industry was mainly represented. Besides, in the research phase, only heavy industrial projects were involved in the testing effort. Therefore, it is essential to extend these research findings to all the construction industry sectors as the index was principally designed for. Due to both the limitations and potential of this research, recommendations for future research have been made. The main recommendation for future research that can be built upon this research followed:

- More Productivity Practices Index scores and project craft productivity data should be collected to validate the index. An improved survey and a larger sample size could allow further analyses in various areas. The availability of more data would enable the deep analysis of the correlation between craft productivity and the level of implementation of selected best productivity practices, which is quantified by Productivity Practices Index project score. A better understanding of this relationship would help the project management team to effectively manage craft productivity implementing the appropriate best productivity practices. This index could be a predictive indicator of craft productivity performances.
- The elements might need to be re-weighted using the analysis of the impact of each element on the different trades' productivity. Indeed, sometimes, the historical data are more reliable than the experts and professional opinions. The last ones can be biased by all the experience they had or the few information they have access due to the very high level of management they

have currently reached. Another Productivity Practices Index elements weighting survey could be conducted involving foremen and people involved in lower management levels.

- Future research programs should include external environment in the development of an index in addition to the management practices. External environments play a very important role and have significant impacts on project craft productivity. Research team highly recommends to develop a more systematic and objective measurement of project craft productivity.
- Future research could add other practices to the index such as the supervisory training which was suggested by the research team and determine their impact on craft productivity. A better understanding of the direct link between productivity practices and craft productivity might be highly valuable for the on-site management team in improving its implementation and planning.

As the world is constantly changing, and the construction industry is not an exception, the RT 252 research program will continue to develop and update the index with the new effective practices.

CONCLUSIONS

Many different factors affect project performance. However, craft productivity is recognized as one of the most important ones. So the critical aspect of construction productivity was the principal motivation of this research. The main research goal was to improve end encourage the effective planning implementation of the practices that positively impact construction productivity. The relationship between best management practices and craft productivity has always been implied. Therefore, the Productivity

Practices Index was developed to assess this link between best management practices and craft productivity and provide an index to the construction industry to easily measure, identify and monitor weak management areas. The definitions of the 53 Productivity Practices Index elements provide a generic checklist to effectively communicate among management levels and manage craft productivity. The project team can easily assess the level of implementation of best productivity practices and craft productivity at any given point in the project phases. The Productivity Practices Index had significant input from both owner and constructor experts and was tested by potential future users.

As discussed earlier, all the initial research objectives were met. The development, refinement, and validation of the Productivity Practices Index model will be pursued in the next phases of the RT 252 research program. In its finished form, the index will be a simple, user-friendly tool to be used during the planning and execution phases of all construction projects.

Appendices

APPENDIX A – RT - 252 ACTIVE TEAM MEMBERS

Warren Adamson, S&B Engineers and Constructors, Ltd.

Maria Benzekri, The University of Texas at Austin

William R. Boyd, Southern Company

Carlos Caldas, The University of Texas at Austin

Daniel D. Christian, Victaulic Company

Laerte Galhardo, Petrobras

Paul M. Goodrum, University of Kentucky

Chris Gouett, University of Waterloo

Robin Granger, Ontario Power Generation

Carl T. Haas, University of Waterloo

George Hoff, Baker Concrete Construction

Shannon D. Hopkins, Eastman Chemical Company

David MacNeel, Baker Concrete Construction

James Matteson, URS Washington Division

Paul Murray, SNC-Lavalin Inc.

Jake Priest, Aker Construction, Inc.

Yongwei Shan, University of Kentucky

Mark Stofega, Fluor Corporation

Carmen Telles, Petrobras

Steve Toon, Bechtel Group, Inc.

Di Zhang, University of Waterloo

Dong Zhai, University of Kentucky

Elements Descriptions

The following descriptions have been developed to help generate a clear understanding of the terms used in the Project Score Sheet located in Appendices A and B. Some descriptions include checklists to clarify concepts and facilitate ideas when scoring each element. Note that theses checklists are not all-inclusive and the user may supplement these list when necessary.

The descriptions are listed in the same order as they appear in the Project Score Sheet. They are organized in a hierarchy by category, section, and element. The Project Score Sheet consists in six main categories, each of which is a series of sections and that have elements. Scoring is performed by evaluating the levels of definition of the elements. The categories, sections and elements are organized as follows:

CATEGORY I - MATERIALS MANAGEMENT

This category consists of the information in respect to material receipt and inspection lay down area planning, procurement management, and delivery plans to address the principles of material logistics. Other areas include controlling and administering the process plan purchases and acquisitions, plan contracting, requesting seller response, selection of sellers, contract administration and contract closure to ensure the project need's are being met in regards to having the necessary construction materials when and where they are needed.

Sections:

A- Material Management Systems
B- Receipt and Inspection of Materials

CATEGORY II - EQUIPMENT LOGISTICS

This category describes best practices in respect to the tools and equipment tracking, maintenance, equipment positioning and lift planning to improve the availability of construction equipment.

Sections:

A- Site Tool Management Best Practices
B- Machinery Availability

CATEGORY III - CRAFT INFORMATION SYSTEMS

This category describes best practices in respect to providing necessary information about how the work should be done.

Sections:

A- Short Interval Planning
B- Work Face Planning
C- Constructability Review

CATEGORY IV - HUMAN RESOURCE MANAGEMENT

This category describes the best practices about how best to leverage the human resources on a project including practices centered on training and development, human behavior, project organization, and employment strategies.

Sections:

A- Training and Development
B- Behavior
C- Organizational Structure
D- Employment

CATEGORY V – CONSTRUCTION METHODS

This category consists of the information in respect to the construction methods that are determined during planning of the project that need to be used to create the highest benefit for the project in terms of productivity.

Sections:

A- Sequence and Scheduling of Work
B- Start-Up, Commission, and Turnover Plan
C- New Product Investigation
D- Site Layout Plan

CATEGORY VI – ENVIRONMENTAL SAFETY AND HEALTH

This category consists of the information in respect to all practices that must be followed to ensure the health and safety of all persons that will be on the jobsite during the construction of the project and in the surrounding community.

Sections:

A- Job Safety
B- Substance abuse Programs
C- Safety Training and Orientation

The following pages contain detailed descriptions for each element and each level of definition in the BPPII.

CATEGORY I - MATERIALS MANAGEMENT

A. MATERIAL MANAGEMENT SYSTEMS BEST PRACTICES

A1. Project team material status database

The project team material status database should consider the following:

- Identify which software system will be used.
- If the database will be accessed by different project participants (e.g. owner, designer, and subcontractors), will it be compatible with existing software systems among each participant.

Level 0	Project team material status database is not applicable
Level 1	No formal paper based system is used to track material status.
Level 2	There is a formal paper based system to track material status.
Level 3	A proprietary internal procurement software tool is used but it is not integrated or used by other contractors.
Level 4	An available software application is used but it is only integrated internally with your company's project control systems.
Level 5	An available software application is used by all contractors that is integrated with your supply chain and other project control systems.

A2. On-site material tracking technology

The project team needs to decide whether an on-site material system will be needed. The decision is partly based on quantity of materials, criticality of schedule, and complexity of project. On-site material tracking technology allows the project team to locate materials in either the warehouse, lay down or staging area or all when needed. Technologies that enable on-site material tracking include:

- Barcodes
- RFID Tags
- Global Positioning Systems

Level 0	On-site material tracking technology is not applicable.
Level 1	No tracking is done on site beyond receivables.
Level 2	Material is assigned a lay down and storage area and the information is recorded.
Level 3	Continuation of 2, plus the location information is kept updated in a software system and well defined and followed processes for developing pick lists, flagging, warehouse organization (if applicable) etc. are established.
Level 4	Continuation of 3, plus the system is supported by tracking software and also supplemented by barcode, GPS, or RFID systems for automated location tracking.
Level 5	Continuation of 4, plus the tracking system is completely automated and integrated with other project processes.

A3. Material delivery schedule

A good material delivery schedule needs to address the following details:

- Dates that material will be received on site
- Dates that the material is required at the site (RAS date)
- Adheres to the material procurement plan
- Quantity of materials that can be stored onsite. If there is little room for storage, the project may need to use a just-in-time delivery schedule.

Level 0	Material delivery schedule is not applicable.
Level 1	There is no documented material delivery schedule
Level 2	Material delivery is planned early in the project and is integrated with a project schedule.
Level 3	Continuation of Level 2 plus the schedule is automatically updated on receipt of new information as procurement proceeds.
Level 4	Continuation of Level 3 plus the schedule is automatically linked with procurement materials management and overall project scheduling systems.
Level 5	Continuation of Level 4 plus material delivery planning and management is completely integrated with other automated project processes including automated materials tracking throughout the supply chain.

A4. Procurement plan for materials and equipment

The procurement scope may include the following:

- Coordinate the construction procurement schedule with the construction schedule
- Facilitate a purchasing system that has the capability of allowing field purchase of consumables.
- Identify items requiring a long lead time for procurement.
- Develop a list of authorized suppliers
- Coordinate with equipment logistics to determine the required at site dates for required rental machinery
- Require fabricator/vendor to take back all cribbing, packaging, and shipping aids when they leave. This will reduce waste removal and promote the reuse of shipping materials.

Level 0	A procurement plan for materials and equipment is not applicable
Level 1	There is no documented procurement plan for materials and equipment.
Level 2	A procurement plan and schedule exists only for large materials and equipment and costly items.
Level 3	Continuation of Level 2, plus plan includes all materials, equipment, and consumables. Also, there is an established protocol for identifying reputation of potential vendors.
Level 4	Continuation of Level 3, plus plan identifies necessary equipment and onsite resources to support delivery.

Level 5	Continuation of Level 4, plus the procurement schedule is automated to a project database that updates as the construction schedule changes

B. RECEIPT AND INSPECTION OF MATERIALS BEST PRACTICES

B1. Material inspection process

It is necessary to have a material inspection process for all deliveries of material to the site. A material inspection process should include the following:

- Organize material receipt inspections immediately upon delivery of material
- Separate material into categorical stages of the receipt process (e.g. awaiting inspection, storage area restocking, scrap, and/or awaiting for shipment)
- Verify if the materials conform to specifications, ASME standards, drawings etc.
- Record the location of the materials and mark the materials for tracking
- Prioritize quality

Level 0	A material inspection process is not applicable
Level 1	There is no material inspection process.
Level 2	A material inspection process is only utilized for large items or the more costly items on a project.
Level 3	Continuation of Level 2, plus it includes all items delivered to the site. There is a lack of organization of the process, and material is not separated into stages of the receipt process nor does it record the location of the materials and mark the materials for tracking
Level 4	Continuation of Level 3, plus inspection are done both at the supplier and onsite, and organizes material receipt inspections immediately upon delivery of material, verifies that materials conform to standards, and organizes materials for tracking.
Level 5	Continuation of Level 4, plus the process includes separation of material into categorical stages of the receipt process (e.g. awaiting inspection, storage area restocking, scrap, and/or awaiting for shipment, verification if the materials conform to specifications, ASME standards, drawings, etc., record of the location of materials and marked materials for tracking, and prioritization quality).

B2. Material inspection team

The people on the inspection team, both onsite and offsite at the suppliers, should be trained and qualified in the following aspects:

- Inspection processes and procedures
- Knowledge of how to inspect materials
- Material specifications (MSDS, material test reports (MTR) etc)

Level 0	Material inspection team is not applicable.
Level 1	There is no material inspection team.
Level 2	There is a designated material inspection team but no training and qualifications of the individual's skill level is specified.
Level 3	Continuations of Level 2, plus inspections are performed by project managers or craft workers rather than the team.

Level 4	Continuation of Level 3, plus the inspection team can adequately inspect materials and understand the material specifications.
Level 5	Continuation of Level 4, plus the members of the inspection team are experts at inspection processes and procedures, and knows how to inspect materials and understands the material specifications.

B3. Post receipt preservation and maintenance

A plan for a complete post receipt preservation and maintenance of the stored material after it has been delivered to the site and passed inspection should be in place for the purpose of knowing the status, location, and maintenance of the material. The inventory of materials should be documented by recording the following characteristics of the stored materials:

- Location
- Preservation of the material after delivery to the jobsite
- Description
- Quality
- Marking

Level 0	Post receipt preservation and maintenance is not applicable
Level 1	There is no post receipt preservation and maintenance plan.
Level 2	There is a plan for post receipt preservation and maintenance.
Level 3	Continuation of Level 2, plus plan is used for large and/or costly items.
Level 4	Continuation of Level 3, plus plan includes all material delivered to the site. A plan for a complete inventory of the material after it has been delivered to the site and passed inspection is in place for the purpose of knowing the status and location of the material. Material is stored in manner so it will be best preserved and maintained.
Level 5	Continuation of Level 4, plus there is a process in place to notify the inspection team of what must be done to preserve and maintain material while in storage. The inventory of materials is documented by recording the following characteristics of the stored materials: location, description, quality, and marking.

CATEGORY II – EQUIPEMENT LOGISTICS

A.SITE TOOL MANAGEMENT BEST PRACTICES

A1. Site tool and consumables management strategy

A successful tool and consumables management strategy is necessary to ensure successful craft productivity. Some issues that need to be addressed are:

- Set up tool distribution strategy (e.g. tool box or tool storage area)
  Tool acquisition strategy that addresses both off-the-shelf (readily available) and custom difficult to acquire) tools
- Decide whether tool management is performed in house or by a third party vendor
- All necessary tools must be properly accounted for before the beginning of the construction phase

Level 0	A site tool and consumables management strategy is not applicable.
Level 1	There is no site tool and consumables management strategy.
Level 2	The use of tool and consumables storage areas has been established.
Level 3	Continuation of Level 2, plus a decision of whether tool management will be performed in-house or by a third party vendor.
Level 4	Continuation of Level 3, plus temporary power requirements for tools have also been established and maintained during construction. Procedures are established to properly account for tools on a weekly or other regularly scheduled basis.
Level 5	Continuation of Level 4 plus includes the commitment of foremen and craft workers to be accountable for the proper care and use of the tools.

A2. Tool tracking systems

Tool tracking systems monitor the location and/or responsible parties for tools when they are checked out from a tool storage area. There will be standard tools used during most jobs, Hammers, screw drivers; crimpers etc, a simple strategy for tool management for these would be lists. Expensive tools, welding machines, jacks, harnesses, and other tools that require maintenance will be tracked using a bar coding process or similar. A tool tracking system may include:

- Developing tool lists considering project requirements
- Using a bar coding system on all small tools and equipment
- Tying a tool to a craftsmen's ID when a tool is checked out.

Level 0	Project tool tracking status database is not applicable
Level 1	There is no database and no formal paper based system to track tools.
Level 2	There is no database, but there is a formal paper based system to track tool tracking status.
Level 3	A software application is used but not integrated with your company's other information technology systems.
Level 4	A software application is used and is integrated with your company's other information technology systems. The system includes bar coding of tools.
Level 5	Continuation of Level 4, plus the system also includes RFID tracking of tools.

A3. On-Site tool maintenance

On-site tool maintenance may include:

- A mechanism for identifying tools that require routine maintenance or replacement of wearable parts
- Tools are maintained to warranty specs throughout the lifecycle of the project
- Established points (e.g. operating hours or duration of tool ownership) when a worn part should be replaced.
- Qualification of tool room personnel to repair and maintain tools

Level 0	On-site tool maintenance is not applicable.
Level 1	There is no documented on-site tool maintenance plan.
Level 2	A mechanism for identifying tools that require routine maintenance or replacement of wearable parts is established.
Level 3	Established points of tool use (e.g. operating hours or duration of tool ownership) are set when tools are inspected for required maintenance.
Level 4	Continuation of Level 3, plus the contract has been established with outside vendor or other personnel offsite to provide required maintenance.
Level 5	Continuation of Level 4, plus qualified and dedicated personnel in the tool room exist to provide tool maintenance and repairs.

A4. Control system for tool delays

Measurement of delays due to tool shortages should be examined by measuring the following occurrences:

- Delay of construction craft workers due to tool shortage (Measurable daily)
- Consideration is given to the level of control versus the cost of the tool (Measurable daily)
- Wait times in tool room lines at the start of each shift or activity (Fixed cost once tool room locations are set)
- Location of tool rooms and amount of tool stock, which influence both craft wait time and lines for tools and travel time to get tools.

Level 0	Control system for tool delays is not applicable
Level 1	There is no control system for tool delays
Level 2	There is no database, but there is a formal paper based system (e.g. foremen delay sampling and activity sampling) to track tool delays
Level 3	There is a regularly updated database that tracks tool delays among craft workers at the construction work face.
Level 4	Continuation of Level 3, plus updates the amount of tool stock available at any one point in time on site.
Level 5	Continuation of Level 4, plus the system is also automatically updated to show which tools are checked out to who on the site.

B.MACHENERY AVAILABILITY BEST PRACTICES

B1. Construction machinery productivity analysis

It is imperative to understand the costs and the benefits that a project will experience from the use of construction machinery and how the availability of the construction machinery affects the cost/benefit ratio. The following actions should be performed:

- Measure utilization time/uptime of equipment
- Measure delays dues to unavailability of construction machinery

Level 0	Use of Construction Machinery is not applicable
Level 1	Construction Machinery is utilized but requirements and usage are not planned and tracked.
Level 2	Machinery requirements are planned and scheduled on a spreadsheet or tracking device but are not tied to a schedule activity. Usage is tracked against a budget activity.
Level 3	Continuations of Level 2, plus needs are reviewed regularly in planning meetings. A mechanism for resolving conflicts and allocation of machinery is established.
Level 4	Continuation of Level 3, plus schedule resource curves are driver in mobilization and demobilization of equipment on site. Schedule is resource leveled with consideration of minimizing in/out cycle of equipment and maximizing use.
Level 5	Continuation of Level 4, plus usage is audited and downtime reported and tracked, equipment schedule/plan adjusted as required based on audits.

B2. Equipment maintenance

Execution of required maintenance is critical to maintain optimum value and efficiency of construction equipment and properly managing routine/scheduled maintenance will minimize project impact due to equipment downtime/failure.

- Will maintenance be completed on site?
- Will maintenance be outsourced?

Level 0	Equipment maintenance is not applicable.
Level 1	Equipment maintenance is not planned for on the project
Level 2	On site equipment is logged in a manual or simplified spreadsheet database. Schedule of required maintenance per type of equipment is identified but not linked to individual construction equipment items with status. Maintenance is done routinely by operator request.
Level 3	Continuation of Level 2, plus equipment is linked to individual construction equipment items with status and maintenance is centrally scheduled and accomplished.
Level 4	Continuation of Level 3, plus a computer based program is utilized for all equipment on site including scheduled and actual on / off site dates, required and accomplished maintenance logs and usage logs.
Level 5	Continuation of Level 4, plus on site or outsourced maintenance is identified with electronic links to required purchase order information. Routine maintenance schedule is electronically updated and maintenance due notices are automatically issued via an email system to required parties.

CATEGORY III – CRAFT INFORMATION SYSTEMS

A.SHORT INTERVAL PLANNING BEST PRACTICES

A1. Short Interval Planning

All elements that are needed to complete construction need to be well organize and included in week, 2-week, and 3-week interval schedules. It is imperative to develop and execute short interval work plans developed by the foremen. The short interval work plans should outline:

- The tasks to be performed
- The numbers of craft workers needed for each task
- The estimate duration for each task
- The required materials, tools and equipment, labor, and project information required to complete each task.

Level 0	The use of short interval plans are not applicable
Level 1	The use of short interval plans has not been addressed.
Level 2	Short interval planning is utilized by taking action based on reported status of on-going activities. Activities in the project schedule are not resource loaded and short interval plans do not detail the required materials, tools and equipment, labor, and required project information.
Level 3	Short interval planning is utilized by detailing the required materials, tools and equipment, labor, and project information required to complete each task. Activities in the project schedule are not resource loaded.
Level 4	Continuation of Level 3, plus activities in the project schedule are resource loaded to help with short interval planning. Short interval plan does consider the effects of craft density due to other area activities and potentially related impacts of congestion and coordination issues.
Level 5	Continuation of Level 4, plus constraints from required deliverables, materials, equipment, labor and information are visible by area.

B.WORK FACE PLANNING BEST PRACTICES

B1. Well defined scope of work

The scope of work must be clear and well defined for all members of the construction project team. Some considerations for defining the scope of work are:

- A clear description of the project's goals
- A clear description of the owner's vision for the facility
- Basic requirements of the project
- The timeframe of all the work involved to produce the project's deliverables

Level 0	A well defined scope of work is not applicable.
Level 1	Work is released to the field on drawings with incomplete design, and execution is

	controlled with a milestone schedule.
Level 2	Continuation of Level 1, plus design is complete. Work is released to the field via drawings without constructability review; execution is controlled with a master schedule.
Level 3	Continuation of Level 2, but with scope and design being complete. Also, Constructability review has been performed and execution is controlled with and integrated schedule.
Level 4	Continuation of Level 3, plus duration for scope of the work package is defined, material availability, testing and inspection requirements are defined, man-hours are charged against the work package, but budget and quantities are not reflected in scope of work.
Level 5	Continuation of Level 4, plus budget, quantities, and man-hours for the scope of work are reflected in the overall schedule. Completion percentage of the work package will be reflected in the integrated schedule.

B2. Utilization of software to assist in generating work packages

Commercially available software can make it easier for the craft worker in the field to access project information. There are several areas that can be assisted with use of this software such as:

- Weekly schedules
- Material delivery
- Identifying materials that are needed for specific on site work packages

Level 0	Utilization of software in generating work packages is not applicable.
Level 1	The project uses a software system to track the generation and closure of work packages. However it is not integrated, material status and drawing status must be entered manually. Work steps are signed off in the package when completed.
Level 2	Continuation of Level 1, plus percent complete is entered by reviewing the package. Work package status is updated to the master schedule manually.
Level 3	Continuation of Level 2, the project uses a software system to generate the work package and automatically includes the drawings and material delivery status. Schedule, percent complete, test and inspection status, and closure must be entered manually by review of the work package.
Level 4	Continuation of Level 3, plus which is updated regularly and automatically includes the provides current design drawing information, updated status of materials, implementation schedule with durations and quantities, test and inspection status, percent complete and closure. Work steps are signed off electronically, however work package status is updated to the master schedule manually.
Level 5	Continuation of Level 4, plus work steps are signed off electronically and work package status is updated electronically.

B3. Project model requirements

4D progress models are a support tool for project planning during the pre-engineering, engineering, procurement, contracts, construction, and turn-over and commissioning to optimize project schedules. This will provide the project:

- A 4D (a linked schedule - 3D model) construction simulation
- Visual construction sequence, which allows integration of construction expertise into project planning and enables visual communication of construction sequence.

Level 0	Project model requirements are not applicable
Level 1	Integration of the projects 3D and schedule information has not been addressed
Level 2	A static 4D Model has been established for the project.
Level 3	Continuation of Level 2 plus includes basic updates manually made based on scheduled changes.
Level 4	Continuation of Level 3, plus the model is dynamic and includes material specifications, change order documentation, and other pertinent design and construction information related to the 4D model.
Level 5	Continuation of Level 4, plus automatically updated based work progress as measured ubiquitously measured by RFID, laser imagining or other technologies is also automatically updated based on scheduled changes.

B4. Dedicated Planner

Hire a person that creates and organizes the plan for the implementation of the Field Installation Work Packages (FIWP). The job of the dedicated planner will include:

- Plan all work necessary to complete the FIWP
- Organize the timelines of all FIWPs
- Allow the field supervision input in all FIWPs
- Field supervision must approve each FIWP

Level 0	Dedicate planner is not applicable
Level 1	Implementation of the FIWP has not been addressed
Level 2	Dedication of single planner or multiple personnel with specific sectional responsibilities based upon project scope, size, and need. Initial planning needs to be coordinated with procurement, planning, and others. High level synchronization driven through utilization of project software.
Level 3	Initiate & maintain communication regarding the confirmation & inspection of all items delivered, outstanding/past due items, FIWP. Update scheduling and management as appropriate. Handle of outstanding, past due items at lowest level, escalate as necessary based upon severity, impact on schedule, past due status timeline.
Level 4	Continuation of Level 3, plus with communication regarding the confirmation & inspection of all items delivered, outstanding/past due items, FIWP. Continued update of scheduling & management. Onsite inspection as necessary regarding the release, tracking, consumption, and back flush of materials. Escalated precedence on outstanding and CCL. Report progressing & audit of progressing, validate to schedule.
Level 5	Continuation of Level 4, plus continued communication of release, tracking, consumption, and back flush of materials. Initiate completion milestone, return to stores unused/not needed materials. Final validation & auditing.

B5. Identify required permitting

Identify required permits and develop procedures for acquiring them in a timely manner on a daily basis. Some examples of permits that may be needed, but not limited to:

- Owner required permits for jobsite access
- City permits
- State permits

Level 0	Identifying required permitting is not applicable
Level 1	Required permitting has not been addressed.
Level 2	Initial investigations based upon projected needs of permits, timeline to attain, how long permit good for, are multiple permits needed, assignment of permit responsibility, sign-off authority, pre-inspection requirements, fees has been completed.
Level 3	Continuation of level 2, plus permit requirements tied to scheduling & milestones.
Level 4	Continuation of Level 3, plus system established for tracking of permit acquisition, release, and closeout driven by requirements and as designated by permit type.
Level 5	Continuation of Level 4, plus system is automatically updated based on continued updates to schedule, permit closeouts, escalation of delays due to permit as deemed necessary dependent on severity of issue & assistance required.

B6. Engineering Work Packages (EWP)

A EWP is an engineering deliverable that is used to develop CWPs and that defines a scope of work to support construction in the form of drawings, procurement deliverables, specifications and vendor support. It is released on an agreed upon sequence consistent with the CWP schedule. The scope of work is typically by discipline by area.

- Identify EWP scope of work
- Develop EWP release schedule
- Develop EWP documents (drawings, procurement deliverables, specifications and vendor support)
- Review and modify EWP before issuing to contractor
- Issue EWP to contractor

Level 0	EWPs are not applicable
Level 1	EWPs have not been addressed.
Level 2	The drawings and specifications are complete; however other EWP documents are not entirely complete. There is no formal review process for EWPs before issuing to the contractor.
Level 3	EWPs are complete including all drawings, procurement deliverables, specifications and vendor support. The contractor experiences many difficulties and requires more information to complete CWPs. Some EWPs have been reviewed and modifications made as required. The review process has been documented.
Level 4	Continuation of Level 3, plus contractor requires little information to complete CWPs. All EWPs have been reviewed and modifications made as required. The review process has been documented.
Level 5	Continuation of Level 4, plus the EWP is easily understandable. The contractor is able to complete CWP with no additional information.

B7. Construction Work Packages (CWP)

A CWP is an executable construction deliverable that defines in detail a specific scope of work and should include a budget and schedule that can be compared with actual performance. The scope of work is such that it does not overlap another CWP. The CWP must include:

- Construction scope of work
- Engineering information
- Craft / Manpower
- Direct Field Equipment and Materials
- Safety
- Quality
- Special Permits / Regulatory Requirements
- Subcontractors
- Vendor Support Data
- Rigging Studies; Scaffolding
- Special Construction Equipment, Tools and Consumables
- Risk Register
- Proposed FIWPs / Related EWPs and CWPs
- Project Controls
- Turnover Documents
- Contact List

Level 0	Completion of CWP's is not applicable
Level 1	Required CWP's have not been addressed.
Level 2	CWPs are partially complete, though there are several sections that remain incomplete. A basic budget and schedule has been completed.
Level 3	All sections of the CWP have been addressed. The sections display no in depth consideration (i.e. one word answers).
Level 4	Continuation of Level 3, plus in depth consideration for most of the sections. A comprehensive schedule and budget has been provided. Completing FIWPs will require more information.
Level 5	Continuation of Level 4, plus all sections have received in depth consideration. The FIWPs can be derived directly from the information provided.

B8. Field Installation Work Packages (FIWP)

A FIWP is a detailed execution plan that ensures all elements necessary to complete the scope of the FIWP are organized and delivered before work is started to enable craft persons to perform quality work in a safe, effective and efficient manner. Generally the scope of work associated with the FIWP should be small enough that it could be completed by a single foremen team in a one or two week time frame. The FIWP must include, but not limited to:

- Timelines must be developed to include the following steps in the FIWP development: identifying, preparing, releasing, and executing. Timeline to include when construction in the field of the FIWP to be started, completed, and float time associated. Further timeline should indicate targets to drive craft performance.
- Scope of work complete with technical data, drawings, and specifications
- Sequence of work and labor required to complete
- List of all materials required
- List of specialty tools, scaffolding and equipment required
- Details quality controls and non-destructive testing methods
- Details risk response plans
- Other FIWP's that may influence the completion of this FIWP

Level 0	Completion of FIWP's is not applicable
Level 1	Required FIWP's have not been addressed.
Level 2	All sections of the FIWP templates are developed, however substantial information is further required for execution.
Level 3	Continuation of level 2, plus little information is required to execute the FIWP.
Level 4	Continuation of Level 3, plus FIWP can be executed completely with information provided. The schedule contains targets that are communicated to craft.
Level 5	Continuation of Level 4, plus the workface planner, field supervisor and foreman attend a “Lessons Learned" session after FIWP execution.

C. CONSTRUCTABILITY REVIEW BEST PRACTICES

C1. Design readiness for construction

Determine that design for all phases of construction is adequate and scheduled to be completed before construction and any relevant phases are mobilized

Level 0	Design readiness for construction is not applicable
Level 1	Design readiness for construction is not addressed
Level 2	Some scheduling and coordination of the phases of construction has been performed by the General Contractor, Construction Manager, or another agent of the Owner.
Level 3	Continuation of Level 2, plus the General Contractor, Construction Manager, or another agent of the Owner has created a detailed schedule for all phases of construction.
Level 4	Continuation of Level 3, plus the owner is more involved and all phases of the project have been determined and the schedule is complete before construction. The schedule

	or sequence of activities may change after construction starts.
Level 5	Continuation of Level 4, plus scheduled to be completed before construction and any relevant phases are mobilized. This scheduling utilizes critical path scheduling, reverse phase scheduling, or some other means of coordination of the project's activities.

C2. PPMOF evaluation

Determine the opportunity for the use of offsite prefabrication, modular construction and preassembly. Determinants for the use of prefabricated, modular, and preassembled components include, but are not limited to:

- Jobsite density
- Limited availability of the local workforce
- Information (e.g. plot plans, contracting strategy and schedule of activities)
- CII's PPMOF is an example of a modular evaluation process that should be utilized.

Level 0	Completion of the PPMOF evaluation is not applicable
Level 1	Opportunities for the use of offsite prefabrication, modular construction and preassembly are unknown.
Level 2	Opportunities for the use of offsite prefabrication, modular construction and preassembly may exist but have not been formally investigated and documented.
Level 3	Members of the constructability review panel are actively searching for opportunities for the use of offsite prefabrication, modular construction and preassembly.
Level 4	Continuation of Level 3 plus identified some opportunities for the use of offsite prefabrication, modular construction and preassembly.
Level 5	Continuation of Level 4, plus all possible opportunities for the use of offsite prefabrication, modular construction and preassembly. Determinants for the use of prefabed, modular, and preassembled components may include: jobsite density, limited availability of local workforce, information (e.g. plot plans, contracting strategy and schedule of activities), and CII's PPMOF.

CATEGORY IV – HUMAN RESOURCE MANAGEMENT

A.TRAINING BEST PRACTICES

A1. Trades technical training

Provide technical training to different trades such as: tool usage, installation procedures, etc...

Level 0	Trades technical training is not applicable.
Level 1	Trades technical training is not addressed.
Level 2	Trades technical training is addressed on the jobsite after the beginning of the project.
Level 3	Trades technical training is provided to a worker when he begins working for the company, and if needed extra training will occur on the job site.
Level 4	Continuation of Level 3, plus craft worker is certified to work in that trade. Before each project new training in the trade will take place if necessary.
Level 5	Continuation of Level 4, plus craft worker takes part in training for new technologies that are introduced in that trade annually and bi-annually.

A2. Career development

Offer career development options such as promotions to employees

Level 0	Career development is not applicable.
Level 1	Career development is not addressed.
Level 2	The organization does not have a formal career development plan for craft workers, but management will discuss future plans with the craft workers.
Level 3	The organization has a formal career development plan for craft workers, but it only addresses short term career developments.
Level 4	Continuation of Level 3, plus it addresses long term career developments and options.
Level 5	Continuation of Level 4, plus addresses the expected performance of the worker and how the performance will affect his/her career development.

B.BEHAVIOR BEST PRACTICES

B1. Recognition Programs

Implement a nonfinancial incentive program based on performance in terms of productivity, quality, and safety. The incentives can be but not limited to:

- Contests
- Visuals (posters and bulletin boards)
- Paid vacation

Level 0	Recognition program is not applicable.
Level 1	Recognition program is not addressed.
Level 2	The organization has an informal recognition program that will recognize craft workers

	occasionally, but not in a formal manner.
Level 3	The organization has a formal recognition program that provides recognition on long term basis.
Level 4	Continuation of Level 3, plus it recognizes craft workers on a regular basis for both positive safety results and good safety behavior.
Level 5	Continuation of Level 4, plus with attending safety meetings and classes. The rewards are given on both short and long term basis, and they are recognized by the upper management of the organization. Each year the recognition program provides a report of the safety performance of the company, discusses how the organization can improve in regard to safety, and constantly looks into tweeking the program to improve it.

B2. Financial Incentive Programs

Implement a financial incentive program based on performance in terms of productivity, quality, and safety.

Level 0	Financial incentive program is not applicable
Level 1	Financial incentive program is not addressed.
Level 2	The organization has an informal incentive program that will recognize craft workers occasionally, but not in a formal manner.
Level 3	The organization has a formal incentive program that provides incentives on long term basis.
Level 4	Continuation of Level 3, plus it provides a monetary bonus for craft workers on a regular basis for both positive safety results and good safety behavior.
Level 5	Continuation of Level 4, plus with attending safety meetings and classes. The rewards are given on both short and long term basis, and they are recognized by the upper management of the organization. Each year the incentive program provides a report of the safety performance of the company, discusses how the organization can improve in regard to safety, and constantly looks into tweeking the program to improve it.

B3. Social Activities

Organizing social activities such as picnic and fishing trip to enhance relationships.

Level 0	Social activities for the craft workers are not applicable.
Level 1	Social activities for the craft workers are not addressed.
Level 2	The organization does not formally plan social activities for the craft workers, and there is only a yearly organization wide social activity.
Level 3	The organization formally plans a social activity for the craft workers once or twice a year in which the project managers will attend, along with a yearly organization wide social activity.
Level 4	Continuation of Level 3, plus several times throughout the year which the project managers will attend, along with a yearly organization wide social activity.
Level 5	Continuation of Level 4, plus monthly which the project managers will attend and upper management including the president will attend on a quarterly basis, along with a yearly organization wide social activity.

C.ORGANIZATIONAL STRUCTURES BEST PRACTICES

C1. Maintain Stability of Organization Structure

Mechanisms to keep organization structure stable, such as:

- Avoid changes in key personnel
- Plans for incorporating any unusual or unplanned staff changes
- There is an individual on site who has the authority to act for the contractor and is in charge of the contractor's work. This person will interface with the counterpart on the owner's team
- Place clauses in the contract that prohibit the replacement of key personnel, unless there is just cause.

Level 0	Maintaining the Stability of the Organizational Structure is Not Applicable.
Level 1	No plans to manage change of key people in contract.
Level 2	Owner & Contractor name/define key individuals in contract.
Level 3	Continuation of Level 2, plus state that they cannot be changed without notice and prior approval.
Level 4	Continuation of Level 3, plus with designated successors (which are pre-approved).
Level 5	Continuation of Level 4, plus contract specifies all key personnel on both Owner & Contractor teams, along with possible successors and right of approval by the other party.

C2. Clear Delegation of Responsibility

Delegation of responsibility/authority applies to both Owner and Contractor and should be understood by both parties. An Owner organization may have many levels of delegation, which may differ depending on whether it is a technical item, construction-related, etc. A Contractor will likely have fewer levels, but not necessarily. To have a successfully executed project, the internal workings of each party must be known and understood to each other.

Level 0	Clear Delegation of Responsibility is Not Applicable.
Level 1	Simple & centralized.
Level 2	Simple & very formal.
Level 3	Stable project environment & more formal.
Level 4	Formal, but differing between technical, admin., etc.
Level 5	There is a formal delegation of authority that is clearly defined for all involved parties. The plan is reviewed periodically and evolves when necessary

D. EMPLOYEMENT PLAN BEST PRACTICES

D1. Retention Plan For Experienced Personnel

It is cost effective to retain experienced craft as opposed to hiring and training new craft. Practices used to retain experienced personnel include an aggressive craft training program that includes programmed pay increases when craft workers become certified, working with craft workers to find employment opportunities on other company projects after their respective work on their current project ends, and offering retention bonuses and preferred hiring status on the next project for the same employer.

Level 0	Retention Plan for Experienced Personnel is Not Applicable.
Level 1	A retention plan is not addressed.
Level 2	Each craft foreman is responsible for his craft retention.
Level 3	Craft training is available but not required. Journeymen have higher pay & preferred hiring status on next project for the same employer.
Level 4	Continuation of Level 3, plus craft training is required for sub-journeymen: testing & certification is available on site. Employer makes available list of opportunities for next project.
Level 5	Continuation of Level 4, plus Craft training for sub-journeymen is required. Testing & certification on site lead to pay increase. Employer meets w/ all individual craft prior to RIF and offers job(s) at new project site(s).

D2. Exit Interview

Conduct exit interview to understand the reasons that drive people leave company

Level 0	Exit Interview is Not Applicable.
Level 1	No exit interview.
Level 2	Exit interview for key craft only.
Level 3	Random exit interviews when there is time.
Level 4	Formal exit interview for all craft.
Level 5	Formal exit interview for all craft and feedback to management about lessons learned how to improve retention when applicable.

CATEGORY V – CONSTRUCTION METHODS

A. SEQUENCE AND SCHEDULING OF WORK BEST PRACTICES

A1. Integrated Schedule Using Critical Path Method (CPM)

"CPM involves scheduling discrete tasks using forward and backward pass techniques. This includes:

- Compare current schedule with the original schedule
- The combination of the two should provide a more reasonable and workable schedule.
- Use critical path method to determine those tasks where overtime will have the greatest effect on the schedule."

Level 0	The use of an integrated schedule using CPM is not applicable.
Level 1	The use of an integrated schedule using CPM has not been addressed
Level 2	Developing a schedule with no resources present and managing schedule status via duration / remaining duration but no link to earned percent complete progress from associated deliverables per activity.
Level 3	Developing a schedule with resources present but no link to earned percent complete progress from associated deliverables per activity.
Level 4	Developing a schedule with resources present but no link to earned percent complete progress from associated deliverables per activity. Resources are updated to reflect current work content (quantity adjustments)
Level 5	Continuation of Level 4 and updated to include quantity adjustments. Earned progress for the activity is based on measured/assessed work complete per deliverable/s per activity. Progress measurement performed in application adapted specifically for deliverable/quantity completed status and earned value calculations, which are appropriately linked to schedule activities.

A2. Work Schedule Strategies

"Different work schedules include standard straight time 40 hour per week schedule (e.g. 5-8 hr days, 4-10 hr day), 2nd and 3rd shifts, overtime schedules (e.g. 5-10 hr days, 6-8 hr days, and 7-10 hr days), and innovative scheduling techniques (e.g. Rolling schedules and 3-13hr days). Try to avoid using overtime if possible, and when overtime is unavoidable, consider the following:

- Schedule overtime, when it is necessary, on alternate weeks rather than continuously.
- Seven 8 hr days is significantly less productive than six 9-hr days even though total hours are about equal. Assume each day involve two lost hours due to lunch, work starts and stoppages, and breaks. "

Level 0	The development of a work schedule strategy is not applicable
Level 1	The development of a work schedule strategy has not been addressed
Level 2	Strategy is based on a single work schedule be it either a straight time 40 hour per week schedule, overtime, or other work schedule
Level 3	Strategy considers multiple work schedules considering critical and near critical activity sequences.
Level 4	Continuation of Level 3, plus strategies' potential impact on worker fatigue, supervision, safety, and absenteeism. The implementation resource of CII Research Team 185 on Cost Effectiveness of Innovative Crew Scheduling is reviewed.
Level 5	Continuation of Level 4, plus each potential strategies' impact analyzed for manpower density and congestion at an area / sub-area level.

A3. Schedule Execution and Management

"Proper attention must be given to the schedule to ensure that the project schedule is being followed. Below are some practices that should be performed to be successful with schedule compliance, but not limited to:

- Measure the actual progress
- Compare with planned schedule
- Update schedule periodically.
- Continuous communication with material suppliers to ensure that material will be onsite when needed"

Level 0	The development of a schedule compliance plan is not applicable
Level 1	The development of a schedule compliance plan has not been addressed
Level 2	Consistent follow up to monitor the following; schedule updated periodically, critical path analysis, progress narrative prepared as required and effective team participation in schedule updates.
Level 3	Continuation of Level 2, plus Quantity reports are regularly performed but rules of completion are not formally defined. Upon request, or as project requires, may include any of the following: change management analysis, risks assessment scenarios/analysis, date variance analysis to approved baseline or previous update period, start / finish percent achieved ratio analysis, communication with material suppliers to ensure material will arrive on site when planned.
Level 4	Continuation of Level 3, plus monitor the following; schedule rigorously updated based on manual input of quantity reports, critical and near critical path analysis, progress narrative prepared and effective team participation in schedule updates. Quantity reports rigorously done by individual(s) trained on formally defined rules of completions. Material suppliers routinely contacted to track status of material delivery dates.
Level 5	Continuation of Level 4, plus will consistently include all of the following, based on project requirements and observed schedule status conditions: change management analysis, risks assessment scenarios/analysis, date variance analysis to approved baseline or previous update period, start / finish percent achieved ratio analysis.

B.START-UP, COMMISION AND TURNOVER BEST PRACTICES

B1. Planning for Start-Up

"The success of a project will heavily depend on the success of the project start up, and the best way to achieve successful project start-up is through thorough planning. A best practice approach to planning for start-up is provided by CII with the 45-Activity Start-up Planning Model. Some of the keys for successful project start-up are, but not limited to:

- Management commitment
- Defining start-up objectives
- Creating a start-up execution plan
- Time outs for analysis"

Level 0	No start-up and commissioning plan exists
Level 1	A partial start-up plan has been assembled but does not provide for buy-in by the operations group, no hazard analysis has been performed, no component/system test protocols have been developed and the plan has not been communicated to affected stakeholders
Level 2	A basic start-up and commissioning plan has been developed and with input and buy-in of management, operations, engineering, safety and other affected employees but the plan has not been implemented.
Level 3	Continuation of Level 2, plus with considerations for interfaces with construction and operations. And commissioning plan has been developed that identifies the objectives and goals of the start-up team with the buy-in of the affected stakeholders.
Level 4	Continuation of Level 3, plus with consideration for cost analysis and detailed scheduling components. The plan is well communicated to all affected employees.
Level 5	Continuation of Level 4, plus with the plan being implemented on the project with proper review by the affected stakeholders for applicability at regular intervals as deemed necessary by the start-up and management teams.

B2. Testing Procedures

As testing of components and system is paramount to the success of a project, the project must institute appropriate testing protocols and procedures.

Level 0	Testing procedures are not applicable to the project
Level 1	The project has not identified required testing procedures or if they have identified the procedures there is no plan to execute them.
Level 2	The project has adequate testing procedures and has partially implemented them on the project
Level 3	Continuation of Level 2, plus testing procedures are detailed and properly documented, and they are implemented on the project.
Level 4	Continuation of Level 3, plus trained all affected employees in their use.
Level 5	Continuation of Level 4, plus testing procedures hare reviewed and approved by the Operations staff and includes appropriate allowances for training of client staff and management.

B3. System Turnover Procedure

System and component turn-over being a key milestone in the project, a formal, documented turnover procedure is required to assure timely and orderly turnover from the various entities of the project

Level 0	The project has no formalized turnover procedure in place
Level 1	A system turnover procedure has not been identified.
Level 2	The project has a turnover procedure that defines the parameters of system completion and delineates the requirements for the turnover of systems from construction to start-up.
Level 3	The project has a formal turnover process that defines the necessary documentation, system boundary identification, parameters of system completion and other parameters of system completion to assure proper turnover of project systems from construction to start-up and from start-up to operations.
Level 4	Continuation of Level 3, plus the procedure has been reviewed and approved by all stakeholders and all affected employees have been properly trained in the process.
Level 5	Continuation of Level 4 plus has the approval of project management and is reviewed for applicability during all phases of the turnover process.

C. NEW TECHNOLOGY INVESTIGATION BEST PRACTICES

C1. New equipment investigation

"New equipment technology is always under development and some new technologies can improve the productivity of project. It is imperative that new technologies are investigated and if they can improve productivity that should be implemented. RT 240 is an example of a tool that evaluates new technology by evaluating:

- Implementation cost
- Technology materials
- Technology usage
- Technology maturity"

Level 0	New equipment investigation is not applicable.
Level 1	New equipment investigation is not addressed.
Level 2	The organization does not a have formal program for the investigation of new equipment. Implementation of new equipment will only occur after the industry-wide implementation.
Level 3	The organization has an informal program for the investigation of the new equipment, and they will investigate the feasibility of the new technologies on a regular basis.
Level 4	The organization has a formal program for the investigation of the new equipment, and they will investigate the feasibility of the new technologies on a regular basis
Level 5	Continuation of Level 4 and they investigate all new equipment technologies using a formal system of rating the new technology, such as the RT-240 tool.

C2. New information system investigation

"New information technology is always under development and some new technologies can improve the productivity of project. It is imperative that new technologies are investigated and if they can improve productivity that should be implemented. RT 240 is an example of a tool that evaluates new technology by evaluating:

- Implementation cost
- Technology materials
- Technology usage
- Technology maturity"

Level 0	New information systems investigation is not applicable.
Level 1	New information systems investigation is not addressed.
Level 2	The project does not a have formal program for the investigation of new information systems. Implementation of new information systems will only occur after the industry-wide implementation.
Level 3	The organization has an informal program for the investigation of the new information systems, and they will investigate the feasibility of the new technologies on a regular basis.
Level 4	Continuation of Level 3, plus the program is formal to investigate new information systems and they will investigate the feasibility of the new technologies on a regular basis.
Level 5	Continuation of Level 4, plus they investigate all new information systems technologies using a formal system of rating the new technology.

C3. New materials technologies Investigation

"New materials technology is always under development and some new materials can improve the productivity of project. It is imperative that new materials are investigated and if they can improve productivity that should be implemented. RT 240 is an example of a tool that evaluates new technology by evaluating:

- Implementation cost
- Technology materials
- Technology usage
- Technology maturity"

Level 0	New materials technologies investigation is not applicable.
Level 1	New materials technologies investigation is not addressed.
Level 2	The project does not a have formal program for the investigation of new materials technologies. Implementation of new information systems will only occur after the industry-wide implementation.
Level 3	The organization has an informal program for the investigation of the new materials

	technologies, and they will investigate the feasibility of the new technologies on a regular basis.
Level 4	Continuation of Level 3, plus the program is formal to investigate new materials technologies and they will investigate the feasibility of the new technologies on a regular basis.
Level 5	Continuation of Level 4, plus they investigate all new materials technologies using a formal system of rating the new technology.

D.SITE LAYOUT PLAN BEST PRACTICES

D1. Dynamic site layout plan

"Dynamic site layout planning allows the project manager to organize the construction site in the most efficient and safe manner. This process should be aided by technology and software applications. This will show real time and future construction sequences visually to examine potential location of space for receipt, storage, or partial assembly of materials. It will assist in alignment and collaboration among construction supervision and material management personnel. The dynamic site layout plan should include all of the necessary construction facilities, which will assure that the project progresses in a smooth manner and interruptions are minimized. The following facilities must be considered:

- Office trailers
- Lunch facilities
- Sanitation and Hygiene
- Field job shacks
- Welding shields
- Weather protection
- Temporary lighting
- Air handling units
- Temporary underground utilities (e.g. telecommunications and sanitary)
- Blast zones
- Heavy haul roads
- Turning radii requirements"

Level 0	Site layout plan is not applicable for the project.
Level 1	A site layout plan has not been addressed.
Level 2	The project team examines the project schedule and assesses when TFs will be brought in.
Level 3	Continuation of Level 2, plus what sizes will be needed prior to the start of the project. No consideration is given to the addition, removal and/or turnover of TFs at different stages of the project. No analysis is done in regards to the layout of the project to optimize locations of the TFs to limit travel time to and from.
Level 4	Continuation of Level 3, plus consideration is given to the addition, removal and/or turnover of TFs at different stages of the project.
Level 5	Continuation of Level 4, plus the team analyzes the layout of the project including where the different parties will be working and place their TFs in the optimum location

	in order to limit travel time to and from TFs.

D2. Site security plan

"Develop a plan to keep the site safe for the workers, the pedestrians or citizens that will operate close to the site, the people that will be making deliveries to the site, and will keep tools and equipment away from situations that will make vandalism and theft easy. The type of project will determine the way the security plan is set up, because a highway construction site in a rural area will have different needs than a high rise building project in an urban environment. Some examples of precautions that need to be taken are:

- Erecting a fence surrounding the site to keep civilians out
- Placing signs outside of the site that warn people of the site
- Set up a security check at the site entrance to ensure only authorized personnel are allowed on site
- Have a security system that will provide access to viewing of the site during all hours of the day
- Badging requirements
- Time keeping"

Level 0	Site security plan is not applicable for the project.
Level 1	Site does not institute security in regards to entry to site, securing commodities, or tools and equipment.
Level 2	The site controls entry and exit from the site, but does not have any other formal security throughout the site.
Level 3	Site has established security procedures including visitor sign in and sign procedure and security guards at every gate. The site has implemented security measures to ensure the preservation of company assets. Protocols have been identified for searches of individuals and their personal property. Searches are conducted randomly.
Level 4	Continuation of Level 3, plus site has ensured that material is not leaving the jobsite by instituting "lock-ups" for items that are prone to theft.
Level 5	Continuation of Level 4, plus the use of electronic security has been implemented such as security cameras.

D3. Equipment positioning strategy

Some typical equipment positioning strategies may include:

- Utilization of crane animation software that examine crane interference, Location and availability
- 3D Modeling/Visualization of construction sequence promotes better understanding of where to locate construction equipment for better utilization and for heavy lifts.
- A Lift plan should be developed base on the following considerations: 1) a construction execution plan that includes sequential erection of a facility and is coordinated with machinery availability; 2) a rigging and heavy haul engineering

study; 3) an evaluation of the need of lifting equipment; 4) an evaluation of the need of elevated platforms

Level 0	Equipment positioning strategy is not applicable.
Level 1	Heavy Rigging and Lifting Studies are accomplished on all critical lifts including evaluation of equipment and rigging selection and crane location. Haul Routes for all heavy transport are evaluated for clearance and load capability.
Level 2	Continuation of Level 1, plus planning includes use of 2D layout and studies to aid in constructability for locating and utilizing equipment.
Level 3	Continuation of Level 2, plus some 3D modeling studies to aid in constructability for locating and utilizing equipment.
Level 4	Continuation of Level 3, plus 3D layout studies to aid in constructability for locating and utilizing equipment.
Level 5	Continuation of Level 4, plus planning includes use of 3D modeling/visualization to aid in constructability for locating and utilizing equipment.

CATEGORY VI - ENVIRONMENTAL SAFETY AND HEALTH

A. JOB SAFETY BEST PRACTICES

A1. Zero Accident Techniques

"The CII Making Zero Accidents a Reality Project Team identified several areas that need to be focused on that will help reduce the number of accidents on the project. Those topic areas are:

- Demonstrated management commitment
- Staffing for safety
- Planning: Pre-project and Pre-task
- Safety education: orientation and specialized training
- Worker involvement
- Evaluation and recognition award
- Subcontract management
- Accident/incident investigations
- Drug and Alcohol testing"

Level 0	Zero Accident Techniques are not applicable to the project
Level 1	No Zero Accident Techniques have been examined and considered for the project.
Level 2	Some Zero Accident Techniques utilized on the project. The project has a reactive approach towards safety.
Level 3	Most but not all Zero Accident Techniques are utilized on the project.
Level 4	All Zero Accident Techniques are utilized on the project.
Level 5	Zero Accident Techniques fully utilized on the project. The project has a very proactive approach towards safety.

A2. Task Safety Analysis

"Task Safety analysis is essential to creating a safe job-site. The following criteria must be met:

- Perform Job Safety Analysis (JSA) on each task on a daily basis
- Determine safety hazards for the specific task
- Take protective measures
- Participation in Safety Task Analysis (e.g. toolbox talks, job safety analyses, stard card). "

Level 0	Task Safety Analysis is not applicable to the project
Level 1	No Task Safety Analysis is utilized
Level 2	Limited Task Safety Analysis is utilized only on high risk areas of the project. The project has a reactive approach towards safety.
Level 3	Most but not all Zero Accident Techniques are utilized on the project.
Level 4	JSAs are utilized daily on the project.

Level 5	JSAs are utilized on daily on the projects on all tasks and some crews perform additional JSA's as task changes.

A3. Identification of Potential Hazards

"All on-site situations that could lead to a hazardous environment for the craft-worker must be identified. Examples of potential hazards are:

- Working at heights
- Soil stability
- Toxic chemical exposure
- Hazard waste disposal
- Environmental hazards"

Level 0	The process for hazard identification process is not applicable on the project.
Level 1	No hazard identification process is in place on the project.
Level 2	Hazards are identified for high risk work only.
Level 3	Hazards are identified for most work.
Level 4	Hazards are identified for the proposed scope of work.
Level 5	Hazards are identified for the proposed scope of work and incorporated into the project's task specific safety planning process.

A4. Housekeeping

Housekeeping includes scheduling weekly times that are taken to ensure that the work face is organized and all materials, tools, and equipment are properly stored to ensure that they are not misplaced and can be easily retrieved for use. These times should be documented on the schedule, and a convenient time to schedule housekeeping sessions is on Friday afternoons or the afternoon on the final day of the work week.

Level 0	Housekeeping is not applicable to the project
Level 1	Regular housekeeping has not been addressed on the project.
Level 2	Housekeeping occurs only after incidents occur.
Level 3	Housekeeping occurs on a bi-weekly scheduled basis.
Level 4	Major travel paths are organized and clean. "Roll backs" are held weekly.
Level 5	All work areas are well organized and designated crews are regularly cleaning

A5. System test hazards planning

At times there can be substances on the job-site that if not handled correctly can be hazardous to humans. Therefore, the people on the site need to be prepared when the substance is being handled, and have measures set up to control the substance in case of an accident. The job-site needs to have criteria for the isolation of work areas due to hazards.

Level 0	No hazard evaluation has been performed
Level 1	A system hazard analysis has been performed but no plan is in place to address the hazards.
Level 2	A system hazard analysis has been performed; a plan has been developed but not communicated to affected staff.
Level 3	Continuation of Level 2, plus it is communicated to affected staff and training of affected employees has been performed and the plan is usually implemented.
Level 4	Continuation of Level 3, plus a plan has been developed with input of the safety department and training of all affected employees has been performed and the procedure is properly implemented.
Level 5	Continuation of Level 4, plus a detailed system hazard analysis has been performed, a plan has been developed with input of the safety department, Start-up group and the operations staff and management that establishes appropriate physical and administrative controls integrating the operations procedures and all start-up and operations employees have been trained and the procedure is properly implemented.

B.SUBSTANCE ABUSE PROGRAMS BEST PRACTICES

B1. Organization drug testing

"The organization must develop a companywide drug testing policy for all employees. The policy should consider using the following:

- Pre employment testing for illegal drugs
- Testing for reasonable cause.
- Post-accident testing for illegal drugs
- Random drug tests for all employees"

Level 0	Organization/Project drug testing is not applicable
Level 1	Organization/Project Drug and Alcohol Testing Policy is not written or publicized.
Level 2	Organization/Project Drug and Alcohol Testing Policy is written and publicized. Policy includes pre-employment testing and post -accident testing.
Level 3	Continuation of Level 2, plus with reasonable cause, project access requirements, and post -accident testing.
Level 4	Continuation of Level 3, plus random selection testing.
Level 5	Continuation of Level 4, plus allows for probable cause searches for drugs and alcohol. Policy also addresses management of prescription drugs used at work. Policy includes provision for confidential treatment or rehabilitation through Employee Assistance programs either voluntary enrollment before a positive test result or mandatory as a condition of future/continued employment.

C.SAFETY TRAINING AND ORIENTATION BEST PRACTICES

C1. OSHA Compliance Training

New employees and current employees who are transferred from another project must attend a project-specific, new-hire safety orientation.

Level 0	OSHA compliance training is not applicable.
Level 1	The project does not have a project specific new hire safety orientation
Level 2	Project specific new hire orientation addresses personal protective equipment, housekeeping and access to site, ladders and safe access to elevated platforms, fall protection, excavations and trenching, tools and equipment, electrical hazards and fire prevention. Supervisors receive additional orientation on behavior or people based safety, conduct of safety meetings, first aid and medical treatment processes, job hazard analysis, consequences for violation of job site work rules and violence, alcohol and drugs in the workplace.
Level 3	Continuation of Level 2, plus all personnel must pass fitness for duty testing prior to attending the project specific new hire safety orientation. Orientation addresses management commitment, general project safety rules, emergency procedures, personal protective equipment, use of ladders and safe access to elevated work areas, hazard communication, housekeeping, fire prevention and protections, barricades, injury/illness reporting, lock-out and tag-out processes, confined spaces, compressed gas cylinders, back injury prevention, excavation and trenching, and hand power tool safety.
Level 4	Continuation of Level 3, plus orientation addresses zero accidents philosophy and general project safety rules.
Level 5	Continuation of Level 4, plus craft workers trained on behavioral based training.

C2. Toolbox safety meetings

Toolbox meeting are conducted frequently to maintain awareness, updated training, and convey important safety and health information.

Level 0	Project does not conduct safety meetings (not applicable)
Level 1	Project issues toolbox topics via handouts to employees on a periodic basis.
Level 2	The project conducts a monthly meeting at or near breaks. Meetings reiterate job site safety rules.
Level 3	The project conducts a weekly meeting at or near breaks. Meetings reiterate job site safety rules.
Level 4	The project conducts weekly meetings at a prearranged time, generally the start of the day. Meetings address current job status and hazards presented by upcoming project activities, corrective actions, review recorded injuries and near misses, or reiterate job site safety rules and expectations. Time is set aside during the meeting for interactive discussion and allows worker feedback.
Level 5	Continuation of Level 4, plus the day of the meeting vary on which they occur, or conducts them daily. Meetings address current job status and hazards presented by upcoming project activities, corrective actions, review recorded injuries and near misses, or reiterate job site safety rules and expectations.

APPENDIX C – PRODUCTIVITY PRACTICES INDEX WEIGHTING SURVEY PACKAGE

Form Email

Subject: CII RT 252 – Productivity Practices Index Weighting Form

Dear Mr./Ms.

Please find attached the Productivity Practices Index weighting form. We have addressed the comments and suggestions received at the last team meeting in Reno. We would greatly appreciate if you could distribute the form to your co-workers. We are planning to collect multiple forms per company, one form per person. As a pilot, we will focus on the companies represented in RT 252. The form includes instructions, however if you have any questions please do not hesitate to contact me at jie.gong@mail.utexas.edu.

Please ask your colleagues to return the completed weight forms electronically, using renamed copies of the attached spreadsheet (eg. Company X – Form A.xls), to jie.gong@mail.utexas.edu. Alternatively, completed forms can be faxed to my attention at (512) 471-3191. We would appreciate if the forms could be completed byAug 24th, 2009.

Best Regards,

<<end of sample email>>

Ph.D. Candidate
Construction Engineering and Project Management Program
Department of Civil, Architectural, and Environmental Engineering
The University of Texas at Austin
Email: jie.gong@mail.utexas.edu
Phone: 806-535-5568

Excel File

Productivity Practices Index Weighting Form

Productivity Practices Index Description:
Some practices that positively impact craft productivity have been known for years (such as workface planning, IT automation and integration, good safety practices, etc.), and yet they are seldom implemented completely or consistently from project to project. Improving implementation of these practices will improve craft productivity. However, we can only improve what we can measure. The Productivity Practices Index is designed as a metric for improving craft productivity. We are starting with practices that are widely accepted on the basis of experience or for which there is strong statistical evidence of impact on craft productivity. To date, CII's research program on craft productivity has identified the processes that are known to positively influence labor productivity. Our next step is to identify the relative importance of the processes in order to help develop a scoring mechanisim of the Productivity Practices Index by having a population of industry experts to complete the following form. Thanks for your support!

Demographic Background:
The following information is needed to allow comparisons among different groups of experts from across the United States and Canada. All of your responses are strictly confidential; individual responses will only be seen by the research team. We appreciate your help in providing this important information.

1. How long have you worked in the construction industry? ___Years (write in the number)

2. What type of organization do you work for?
__Construction firm __Owner __Vendor __Other (please describe) ___________________________________

3. What is your primary scope of work?
__Project Control __Materials Management __Safety __Human Resource Management
__Site Management __Training Professional __Estimator
__Other (please describe) ___________________________________

4. How long have you served in this position? ___Years (write in the number)

5. The workforce in your organization is primarily
__Union __Open Shop __Both

6**. Industry Sector** – Which construction sector best describes your company's work? If more than one sector applies, please rank order the sector that apply in order of current volume of work, with 1 being the largest, 2 being the next largest, and so on.

_____ **Heavy Industry (**including Chemical Manufacturing, Electrical (Generating), Environmental, Metals Refining/Processing, Mining, Natural Gas Processing, Oil Exploration/Production, Oil Refining, and Pulp and Paper)
_____ **Light Industry (**including Automotive Assembly, Consumer Products Manufacturing, Foods, Microelectronics Manufacturing, Office Products Manufacturing, and Pharmaceutical Manufacturing)
_____ **Building (**including Communications Center, Dormitory/Hotel, Low-rise Office (≤3 floors), High-rise Office (>3 floors), Hospital, Housing, Laboratory, Maintenance Facilities, Parking Garage, Physical Fitness Center, Restaurant/Nightclub, Retail Building, School, Warehouse, Residential, Prison, and Movie Theatre)
_____ **Infrastructure (**including Airport, Electrical Distribution, Flood Control, Highway, Marine Facilities, Navigation, Rail, Tunneling, Water/Wastewater, Pipeline, Gas Distribution, Telecom, and Wide Area Network)

7**. Geographic Region** – What region of North America do you primarily work in. If more than one region applies, please rank the order in which the regions apply in terms of current volume of work, with 1 being the largest, 2 being the next largest, and so on.

<u>United States</u>
___Northeastern US (includes CT, ME, MA, NH, RI, VT, NJ, NV, and PA)
___ Midwestern US (includes IL, IN, MI, OH, WI, ND, SD, IA, KS, MN, MO, NE)
___ Western US (Includes AZ, CO, ID, MT, NV, UT, WY, NM, AK, CA, HI, OR, and WA)
___ Southern US (includes KY, TN, AR, OK, DE, DC, GA, MD, NC, SC, VA, and WV)
___ Gulf Coast US (includes AL, MS, LA, TX, FL)
<u>Canada</u>
___ Atlantic Provinces (includes NL, PEI, NS, and NB)
___ Quebec
___ Ontario
___ Prairie Provinces (Includes MB, SK, and AB)
___ British Columbia
___ Territories (Includes YT, NT, and NU).

Demographic Background:
The following information is needed to allow comparisons among different groups of experts from across the United States and Canada. All of your responses are strictly confidential; individual responses will only be seen by the research team. We appreciate your help in providing this important information.

1. How long have you worked in the construction industry? ___Years (write in the number)

2. What type of organization do you work for?
__Construction firm __Owner __Vendor __Other (please describe) ______________________

3. What is your primary scope of work?
__Project Control __Materials Management __Safety __Human Resource Management
__Site Management __Training Professional __Estimator
__Other (please describe) ______________________

4. How long have you served in this position? ___Years (write in the number)

5. The workforce in your organization is primarily
__Union __Open Shop __Both

6**. Industry Sector** – Which construction sector best describes your company's work? If more than one sector applies, please rank order the sector that apply in order of current volume of work, with 1 being the largest, 2 being the next largest, and so on.

_____ **Heavy Industry (**including Chemical Manufacturing, Electrical (Generating), Environmental, Metals Refining/Processing, Mining, Natural Gas Processing, Oil Exploration/Production, Oil Refining, and Pulp and Paper)
_____ **Light Industry (**including Automotive Assembly, Consumer Products Manufacturing, Foods, Microelectronics Manufacturing, Office Products Manufacturing, and Pharmaceutical Manufacturing)
_____ **Building (**including Communications Center, Dormitory/Hotel, Low-rise Office (≤3 floors), High-rise Office (>3 floors), Hospital, Housing, Laboratory, Maintenance Facilities, Parking Garage, Physical Fitness Center, Restaurant/Nightclub, Retail Building, School, Warehouse, Residential, Prison, and Movie Theatre)
_____ **Infrastructure (**including Airport, Electrical Distribution, Flood Control, Highway, Marine Facilities, Navigation, Rail, Tunneling, Water/Wastewater, Pipeline, Gas Distribution, Telecom, and Wide Area Network)

7**. Geographic Region** – What region of North America do you primarily work in. If more than one region applies, please rank the order in which the regions apply in terms of current volume of work, with 1 being the largest, 2 being the next largest, and so on.

United States
___Northeastern US (includes CT, ME, MA, NH, RI, VT, NJ, NV, and PA)
___ Midwestern US (includes IL, IN, MI, OH, WI, ND, SD, IA, KS, MN, MO, NE)
___ Western US (Includes AZ, CO, ID, MT, NV, UT, WY, NM, AK, CA, HI, OR, and WA)
___ Southern US (includes KY, TN, AR, OK, DE, DC, GA, MD, NC, SC, VA, and WV)
___ Gulf Coast US (includes AL, MS, LA, TX, FL)
Canada
___ Atlantic Provinces (includes NL, PEI, NS, and NB)
___ Quebec
___ Ontario
___ Prairie Provinces (Includes MB, SK, and AB)
___ British Columbia
___ Territories (Includes YT, NT, and NU).

Weighting Form Filling Instructions

Steps: ***For each GROUP below***
1. Find the LEAST IMPORTANT as the baseline for comparison, and assign IMPORTANCE FACTOR 1
2. Find the MOST IMPORTANT factor as the baseline for comparison, and assign IMPORTANCE FACTOR 5
3. Assign the importance factor for the other items in the group considering their relative importance

Importance Factor:
Possible Values: 1 - 2 - 3 - 4 - 5

Item Description:
Each item in the group comes with a description. Point your mouse on the item without pressing any mouse button and a description will appear.

Productivity Practices Index CATEGORIES

Group 1		Importance Factor
	I - MATERIALS MANAGEMENT	
	II - EQUIPMENT LOGISTICS	
	III - CRAFT INFORMATION SYSTEMS	
	IV - HUMAN RESOURCE MANAGEMENT	
	V - CONSTRUCTION METHODS	
	VI - ENVIRONMENTAL SAFETY AND HEALTH	

Group 2	I - MATERIALS MANAGEMENT	Importance Factor
	A. Materials Management Systems	
	B. Receipt and Inspection of Materials	

Group 3	A. Materials Management Systems	Importance Factor
	1. Project team material status database	
	2. On-site material tracking technology	
	3. Material delivery schedule	

	4. Procurement plan for materials and equipment	

Group 4	B. Receipt and Inspection of Materials	Importance Factor
	1. Material inspection process	
	2. Material inspection team	
	3. Post receipt preservation and maintenance	

Productivity Practices Index EQUIPMENT LOGISTICS CATEGORY

Group 5	II - EQUIPMENT LOGISTICS	Importance Factor
	A. Site Tool Management	
	B. Machinery Availability	

Group 6	A. Site Tool Management	Importance Factor
	1. Site tool and consumables management strategy	
	2. Tool tracking systems	
	3. On-Site tool maintenance	
	4. Control system for tool delays	

Group 7	B. Machinery Availability	Importance Factor
	1. Construction machinery productivity analysis	
	2. Equipment maintenance	

Productivity Practices Index CRAFT INFORMATION SYSTEMS CATEGORY

Group 8	III - CRAFT INFORMATION SYSTEMS	Importance Factor
	A. Short Interval Planning	
	B. Work Face Planning	
	C. Constructability Review	

Group 9	B. Work Face Planning	Importance Factor
	1. Well defined scope of work	
	2. Utilization of software to assist in generating work packages	
	3. Project model requirements	
	4. Dedicated Planner	
	5. Identify required permitting	
	6. Engineering Work Packages (EWP)	
	7. Construction Work Packages (CWP)	
	8. Field Installation Work Packages (FIWP)	

Group 10	C. Constructability Review	Importance Factor
	1. Design readiness for construction	
	2. PPMOF evaluation	

Productivity Practices Index HUMAN RESOURCE MANAGEMENT CATEGORY

Group 11	IV - HUMAN RESOURCE MANAGEMENT	Importance Factor
	A. Training and Development	
	B. Behavior	
	C. Organizational Structure	
	D. Employment	

Group 12	A. Training and Development	Importance Factor
	1. Trades technical training	
	2. Career development	

Group 13	B. Behavior	Importance Factor
	1. Nonfinancial Reward and Recognition Programs	
	2. Financial Reward and Recognition Programs	

	3. Social Activities	

Group 14	C. Organizational Structure	Importance Factor
	1. Maintain Stability of Organization Structure	
	2. Clear Delegation of Responsibility	

Group 15	D. Employment	Importance Factor
	1. Retention Plan For Experienced Personnel	
	2. Exit Interview	

Productivity Practices Index CONSTRUCTION METHODS CATEGORY

Group 16	V - CONSTRUCTION METHODS	Importance Factor
	A. Sequence and Scheduling of Work	
	B. Start-Up, Commission, and Turnover Plan	
	C. New Product Investigation	
	D. Site Layout Plan	

Group 17	A. Sequence and Scheduling of Work	Importance Factor
	1. Integrated Schedule Using Critical Path Method (CPM)	
	2. Work Schedule Strategies	
	3. Schedule Execution and Management	

Group 18	B. Start-Up, Commission, and Turnover Plan	Importance Factor
	1. Planning for Start-Up	
	2. Testing Procedures	
	3. System Turnover Procedure	

Group 19	C. New Product Investigation	Importance Factor
	1. New equipment investigation	

	2. New information system investigation	
	3. New materials technologies Investigation	

Group 20	D. Site Layout Plan	Importance Factor
	1. Dynamic site layout plan	
	2. Site security plan	
	3. Equipment positioning strategy	

Productivity Practices Index ENVIRONMENTAL SAFETY AND HEALTH CATEGORY

Group 21	VI - ENVIRONMENTAL SAFETY AND HEALTH	Importance Factor
	A. Job Safety	
	B. Substance Abuse Programs	
	C. Safety Training and Orientation	

Group 22	A. Job Safety	Importance Factor
	1. Zero Accident Techniques	
	2. Task Safety Analysis	
	3. Identification of Potential Hazards	
	4. Housekeeping	
	5. System test hazards planning	

Group 23	B. Substance Abuse Programs	Importance Factor
	1. Pre-employment Drug Testing	
	2. After-employment Drug Testing	

Group 24	C. Safety Training and Orientation	Importance Factor
	1. OSHA Compliance Training	
	2. Toolbox safety meetings	

APPENDIX D - PARTICIPATING COMPANIES

Aker

Bechtel, Inc

Eastman Chemical Company

Fluor Corporation

Ontario Power Generation

Petrobras

S&B Engineers & Constructors Ltd.

SNC-Lavalin

Washington division of URS

APPENDIX E – IMPORTANT FACTORS OF CATEGORIES, SECTIONS AND ELEMENTS

Group	CATEGORIES	Importance Factor	Points	
Group 1	I - MATERIALS MANAGEMENT	3.62	357	
	II - EQUIPMENT LOGISTICS	2.97	293	
	III - CRAFT INFORMATION SYSTEMS	2.99	295	
	IV - HUMAN RESOURCE MANAGEMENT	2.86	282	
	V - CONSTRUCTION METHODS	3.84	378	
	VI - ENVIRONMENTAL SAFETY AND HEALTH	4.00	394	
			Sum	2000

Group	I - MATERIALS MANAGEMENT	Importance Factor	Points	
Group 2	A. Materials Management Systems	3.70	196	
	B. Receipt and Inspection of Materials	3.04	161	
			Sum	357

Group	A. Materials Management Systems	Importance Factor	Points	
Group 3	1. Project team material status database	2.54	36	
	2. On-site material tracking technology	3.14	45	
	3. Material delivery schedule	4.09	59	
	4. Procurement plan for materials and equipment	3.90	56	
			Sum	196

Group	B. Receipt and Inspection of Materials	Importance Factor	Points	
Group 4	1. Material inspection process	4.05	63	
	2. Material inspection team	3.06	48	
	3. Post receipt preservation and maintenance	3.25	50	
			Sum	161

Group	II - EQUIPMENT LOGISTICS	Importance Factor	Points	
Group 6	A. Site Tool Management	2.80	120	
	B. Machinery Availability	4.03	173	
			Sum	293

Group 7	A. Site Tool Management	Importance Factor	Points	
	1. Site tool and consumables management strategy	4.12	38	
	2. Tool tracking systems	3.10	29	
	3. On-Site tool maintenance	3.05	28	
	4. Control system for tool delays	2.73	25	
			Sum	120

Group 8	B. Machinery Availability	Importance Factor	Points	
	1. Construction machinery productivity analysis	2.55	67	
	2. Equipment maintenance	4.02	106	
			Sum	173

Group 9	III - CRAFT INFORMATION SYSTEMS	Importance Factor	Points	
	A. Short Interval Planning	2.67	74	
	B. Work Face Planning	4.05	113	
	C.Constructability Review	3.86	108	
			Sum	295

Group 11	B. Work Face Planning	Importance Factor	Points	
	1. Well defined scope of work	4.66	19	
	2. Utilization of software to assist in generating work packages	2.59	11	
	3. Project model requirements	2.92	12	
	4. Dedicated Planner	3.58	15	
	5. Identify required permitting	3.17	13	
	6. Engineering Work Packages (EWP)	3.48	14	
	7. Construction Work Packages (CWP)	3.69	15	
	8. Field Installation Work Packages (FIWP)	3.66	15	
			Sum	113

Group 13	C.Constructability Review	Importance Factor	Points	
	1. Design readiness for construction	4.29	67	
	2. PPMOF evaluation	2.56	40	
			Sum	108

Group 14	IV - HUMAN RESOURCE MANAGEMENT	Importance Factor	Points	
	A. Training and Development	3.87	79	
	B. Behavior	3.34	68	
	C. Organizational Structure	3.30	68	
	D. Employment	3.28	67	
			Sum	282

Group 15	A. Training and Development	Importance Factor	Points	
	1. Trades technical training	3.83	47	
	2. Career development	2.70	33	
			Sum	79

Group 16	B. Behavior	Importance Factor	Points	
	1. Nonfinancial Incentive Programs	3.35	24	
	2. Financial Incentive Programs	3.80	28	
	3. Social Activities	2.25	16	
			Sum	68

Group 17	C. Organizational Structure	Importance Factor	Points	
	1. Maintain Stability of Organization Structure	3.15	32	
	2. Clear Delegation of Responsibility	3.59	36	
			Sum	68

Group 18	D. Employment	Importance Factor	Points	
	1. Retention Plan For Experienced Personnel	4.43	46	
	2. Exit Interview	2.03	21	
			Sum	67

Group 19	V - CONSTRUCTION METHODS	Importance Factor	Points	
	A. Sequence and Scheduling of Work	4.57	124	
	B. Start-Up, Commission, and Turnover Plan	3.62	98	
	C. New Product Investigation	1.97	54	
	D. Site Layout Plan	3.76	102	
			Sum	378

Group 20	A. Sequence and Scheduling of Work	Importance Factor	Points	
	1. Integrated Schedule Using Critical Path Method (CPM)	4.03	48	

		Importance Factor	Points	
	2. Work Schedule Strategies	2.54	30	
	3. Schedule Execution and Management	3.84	46	
			Sum	124

		Importance Factor	Points	
Group 21	B. Start-Up, Commission, and Turnover Plan			
	1. Planning for Start-Up	3.80	36	
	2. Testing Procedures	3.02	28	
	3. System Turnover Procedure	3.59	34	
			Sum	98

		Importance Factor	Points	
Group 22	C. New Product Investigation			
	1. New equipment investigation	3.42	20	
	2. New information system investigation	2.79	16	
	3. New materials technologies investigation	3.14	18	
			Sum	54

		Importance Factor	Points	
Group 23	D. Site Layout Plan			
	1. Dynamic site layout plan	3.65	38	
	2. Site security plan	2.76	29	
	3. Equipment positioning strategy	3.45	36	
			Sum	102

		Importance Factor	Points	
Group 24	VI - ENVIRONMENTAL SAFETY AND HEALTH			
	A. Job Safety	4.49	162	
	B. Substance Abuse Programs	2.43	88	
	C. Safety Training and Orientation	3.99	144	
			Sum	394

		Importance Factor	Points	
Group 25	A. Job Safety			
	1. Zero Accident Techniques	4.27	38	
	2. Task Safety Analysis	4.09	36	
	3. Identification of Potential Hazards	3.79	34	
	4. Housekeeping	3.48	31	
	5. System test hazards planning	2.66	24	
			Sum	162

		Importance Factor	Points	
Group 27	C. Safety Training and Orientation			

	1. OSHA Compliance Training	2.95	62	
	2. Toolbox safety meetings	3.91	82	
			Sum	144

Appendix F – Productivity Practices Index Elements Weights

I - MATERIALS MANAGEMENT							
Section							Score
Element	0	1	2	3	4	5	
A. Materials Management Systems							
1. Project team material status database	0	1	10	19	28	36	
2. On-site material tracking technology	0	1	12	23	34	45	
3. Material delivery schedule	0	1	15	29	43	59	
4. Procurement plan for materials and equipment	0	1	15	29	43	56	
Total Maximum Score of Material Management Systems Section						**196**	
B. Receipt and Inspection of Materials							
1. Material inspection process	0	1	16	31	46	63	
2. Material inspection team	0	1	13	25	37	48	
3. Post receipt preservation and maintenance	0	1	13	25	37	50	
Total Maximum Score of Receipt and Inspection of Materials Section						**161**	
Overall Material Management score :							

II - EQUIPMENT LOGISTICS							
Section	Definition Level						Score
Element	0	1	2	3	4	5	
A. Site Tool Management							
1. Site tool and consumables management strategy	0	1	10	19	28	38	
2. Tool tracking systems	0	1	8	15	22	29	
3. On-Site tool maintenance	0	1	8	15	22	28	
4. Control system for tool delays	0	1	7	13	19	25	
Total Maximum Score of Site Tool Management Section						**120**	
B. Machinery Availability							
1. Construction machinery productivity analysis	0	1	17	33	49	67	
2. Equipment maintenance	0	1	27	53	79	106	
Total Maximum Score of Machinery Availability Section						**173**	
Overall Equipment Logistic Score :							

III - CRAFT INFORMATION SYSTEMS							
Section	Definition Level						Score
Element	0	1	2	3	4	5	

A. Short Interval Planning							
1. Short Interval Planning	0	1	19	37	55	74	
Total Maximum Score of Short Interval Planning Section						**74**	
B. Work Face Planning							
1. Well defined scope of work	0	1	5	9	13	19	
2. Utilization of software to assist in generating work packages	0	1	3	5	7	11	
3. Project model requirements	0	1	4	7	10	12	
4. Dedicated Planner	0	1	4	7	10	15	
5. Identify required permitting	0	1	4	7	10	13	
6. Engineering Work Packages (EWP)	0	1	4	7	10	14	
7. Construction Work Packages (CWP)	0	1	4	7	10	15	
8. Field Installation Work Packages (FIWP)	0	1	4	7	10	15	
Total Maximum Score of Work Face Planning Section						**114**	
C. Constructability Review							
1. Design readiness for construction	0	1	17	33	49	67	
2. PPMOF evaluation	0	1	11	21	31	40	
Total Maximum Score of Construction Review Section						**107**	
Overall Craft Information Systems Score :							

IV - HUMAN RESOURCE MANAGEMENT							
Section							Score
Element	0	1	2	3	4	5	
A. Training and Development							
1. Trades technical training	0	1	12	23	34	47	
2. Career development	0	1	9	17	25	33	
Total Maximum Score of Training and Development Section						**80**	
B. Behavior							
1. Recognition Programs	0	1	7	13	19	24	
2. Financial Incentive Programs	0	1	8	15	22	28	
3. Social Activities	0	1	5	9	13	16	
Total Maximum Score of Behavior Section						**68**	
C. Organizational Structure							
1. Maintain Stability of Organization Structure	0	1	9	17	25	32	
2. Clear Delegation of Responsibility	0	1	10	19	28	36	
Total Maximum Score of Organizational Structure Section						**68**	
D. Employment							
1. Retention Plan For Experienced Personnel	0	1	12	23	34	46	

2. Exit Interview	0	1	6	11	16	21	
Total Maximum Score of Employment Section						**67**	
Overall Human Resource Management Score :							

V - CONSTRUCTION METHODS							
Section							Score
Element	0	1	2	3	4	5	
A. Sequence and Scheduling of Work							
1. Integrated Schedule	0	1	13	25	37	48	
2. Work Schedule Strategies	0	1	8	15	22	30	
3. Schedule Execution and Management	0	1	12	23	34	46	
Total Maximum Score of Sequence and Scheduling of Work Section						**124**	
B. Start-Up, Commission, and Turnover Plan							
1. Planning for Start-Up	0	1	10	19	28	36	
2. Testing Procedures	0	1	8	15	22	28	
3. System Turnover Procedure	0	1	9	17	25	34	
Total Maximum Score of Start-Up, Commission and Turnover Plan Section						**98**	
C. New Product Investigation							
1. New equipment investigation	0	1	6	11	16	20	
2. New information system investigation	0	1	5	9	13	16	
3. New materials technologies Investigation	0	1	5	9	13	18	
Total Maximum Score of New Product Investigation Section						**54**	
D. Site Layout Plan							
1. Dynamic site layout plan	0	1	10	19	28	38	
2. Site security plan	0	1	8	15	22	29	
3. Equipment positioning strategy	0	1	10	19	28	36	
Total Maximum Score of Site Layout Plan Section						**103**	
Overall Construction Methods Score :							

VI - ENVIRONMENTAL SAFETY AND HEALTH							
Section							**Score**
Element	**0**	**1**	**2**	**3**	**4**	**5**	
A. Job Safety							
1. Zero Accident Techniques	0	1	10	19	28	38	
2. Task Safety Analysis	0	1	10	19	28	36	
3. Identification of Potential Hazards	0	1	9	17	25	34	
4. Housekeeping	0	1	8	15	22	31	

5. System test hazards planning	0	1	7	13	19	24	
Total Maximum Score of Job Safety Section						**163**	
B. Substance Abuse Programs							
1. Substance Abuse Programs	0	1	23	45	67	88	
Total Maximum Score of Substance Abuse Programs Section						**88**	
C. Safety Training and Orientation							
1. OSHA Compliance Training	0	1	16	31	46	62	
2. Toolbox safety meetings	0	1	21	41	61	82	
Total Maximum Score of Safety Training and Orientation Section						**144**	
Overall Environmental Safety and Health Score :							

APPENDIX G – PRODUCTIVITY PRACTICES INDEX TESTING SURVEY PACKAGE

BM&M Project Cover Letter
Organization:
Benchmarking Associate & Project Manager:
Project Name:
Date: March, 26th 2010

Dear []:

The Construction Industry Institute (CII) is sponsoring a research project, RT 252 Craft Productivity Research Program, which aims to identify and validate initiatives, techniques, practices, or methods that, if implemented, would result in significant craft productivity improvements.

We are asking you to participate in this survey because you have previously submitted construction productivity data to CII's Benchmarking and Metrics (BM&M) program. As an incentive, your organization will receive an individual report with a summary of your results, including a comparison with the results from other projects that participated in this survey, as well as recommendations and conclusions.

Enclosed are survey instruments that will provide us information from the **project identified above**. The questionnaire should require approximately one to two hours. All responses will be held in strict confidence. Only the research staff at our universities will have access to the information collected.

The survey package is color-coded and includes a brief introduction to the Productivity Practices Index (blue), the Productivity Practices Index Questionnaire (white), and the Productivity Practices Index Elements Description (yellow). *Please complete the white Productivity Practices Index Questionnaire and return it* ***by April, 23rd*** *in the self addressed, stamped envelope provided.* The rest of the material is enclosed for your information and does not need to be returned. If you have any questions regarding the questionnaire or the research project in general, please feel free to contact Carlos Caldas at (512) 471-6014 (caldas@mail.utexas.edu) or Maria Benzekri at (512) 563-6793, (maria.benzekri@gmail.com).

Your participation in this effort is greatly appreciated by the research team and the Construction Industry Institute. You will be making a significant contribution toward the development and validation of the Productivity Practices Index. We expect that the research findings as well as the Productivity Practices Index publications that will be provided to you in the future will directly help you in enhancing your craft productivity.

Sincerely,

Carlos H. Caldas, Ph.D	Carl T. Haas, Ph.D	Paul Goodrum, Ph.D
Associate Professor	Professor	Associate Professor
The University of Texas at Austin	University of Waterloo	University of Kentucky

Enclosed (3)
Productivity Practices Index Introduction
Productivity Practices Index Questionnaire
Productivity Practices Index Elements Descriptions

Productivity Practices Index

Introduction

Based on casual observation of typical jobsites, it unfortunately becomes evident that most projects are not implementing historically successful productivity practices. If such practices could be documented and incorporated into one resource, the product would be an overall roadmap about how to effectively manage and improve construction productivity. Such a resource in and of itself would be a significant productivity innovation to construction.

A capital project needs to ensure that its productivity is being effectively managed. To meet this objective, Research Team 252 began the process of developing the Productivity Practices Index. The Productivity Practices Index outlines a new process for building the foundation of the essential practices needed to ensure high levels of productivity by the craft workers. The practices included are those that are widely accepted throughout the construction industry to have a positive impact on craft worker productivity. Some practices that positively impact craft productivity have been known for years, such as materials management, work packaging, IT automation and integration, and yet they are seldom implemented completely or consistently from project to project. Improving implementation of these practices will improve craft productivity. However, one can only improve what one can measure. The Productivity Practices Index is envisioned as a process and metric for measuring the implementation level of practices that have the potential to improve craft productivity. RT-252 started by identifying practices that are widely accepted on the basis of experience or for which there is strong statistical evidence of impacting craft productivity. Validation of the metric is requiring acquisition of project or activity level craft productivity data to evaluate the strength of the relationship between the metric and craft productivity.

Value- Added Benefits

A significant feature of the Productivity Practices Index is that it can be utilized to fit the needs of almost any individual project, small or large. The Productivity Practices Index is:

- A listing of the essential elements that need to be planned and implemented in a project.
- A checklist that a project team can use for determining the level of implementation of best productivity practices.
- A listing to develop strategies for the implementation of best productivity practices.
- A benchmarking tool for organizations to use in evaluation completion of effective managed productivity versus the performance of past projects.

Methodology

The development of the Productivity Practices Index began by using the knowledge and experience of the members of the research team and studies that have validated management practices that improve craft worker productivity. Each of the practices is organized into sections that include similar practices. Each section has an audit form that includes the practices that are included in that section. Each category includes between 2 and 4 sections. The sections that are included in each category are similar and related, but not the same. An example is Category I – Materials Management, which has two sections: 1) Materials Management Systems and 2) Receipt and Inspection of Materials. The Productivity Practices Index includes 6 Categories, which contain 18 sections. These sections also are divided into elements. A complete list of the Productivity Practices Index's six categories, 18 sections and 53 elements is given in the Validation Questionnaire. Approximately 30 pages of detailed descriptions have been developed to support completion of the scope.

Steps remaining in the development effort include:

1. Validating the tool through testing on sample projects
2. Developing publications and deploying to industry

Products of the Research

A research report, research summary and implementation resource of the BPPII will be completed by 2012.

Productivity Practices Index Questionnaire

Validation Questionnaire
Productivity Practices Index

Construction Industry Institute (CII) Research Team 252
Project Name:

1. Project Rating Information:

Next, please complete the Project Rating Information located on the next few pages. Detailed instructions for completing this form are explained below.

INSTRUCTIONS FOR RATING A PROJECT

The Productivity Practices Index is intended to measure the implementation levels of practices that can improve craft productivity. The Productivity Practices Index is intended to be used during the construction phase. When rating a project, the team involved in the construction phase should consider the **average level of implementation of each element** in Productivity Practices Index across the duration of the construction phase of the project.

The Productivity Practices Index consists of six mains categories, each of which is broken down into a series of sections which, in turn, are further broken down into elements. Scoring is performed by evaluating and rating the individual elements. Element should be rated numerically from 0 to 5 based on its average level of planning and implementation during the construction phase.

To asses an element, first refer to the Project Score Sheet (white).
Next, read its corresponding description in the Description section of the 53 Productivity Practices Index Elements Description document (yellow).
The elements contain a list of items to be considered when evaluating their level of definition. These lists can be used as checklists.

Please choose only one definition level (0, 1, 2, 3, 4, or 5) for that element based on the perception of how well it has been addressed. All elements are well described and all different levels have a specific definition for each element. Thus all participants will understand the elements. Once the appropriate definition level for the element is chosen, **please check (√) the corresponding box.** Do this for all the 53 elements in the Project Score Sheet. Be sure to assess each element.

Example: How to assess "Project team material status database" element?

1. Look at the project score sheet

MATERIALS MANAGEMENT

Section						
Element	0	1	2	3	4	5
A. Materials Management Systems						
1. Project team material status database *(p4)*						
2. On-site material tracking technology *(p4)*						

(p4) refers to the Productivity Practices Index Elements Descriptions document (Yellow).

2. Go to page 4 in the Productivity Practices Index Element Description document (Yellow) and read the element definition

A1. Project team material status database
The project team material status database should consider the following:
- Identify which software system will be used.
- If the database will be accessed by different project participants (e.g. owner, designer, and subcontractors), will it be compatible with existing software systems among each participant.

3. Collect data that you may need
4. Analyze the level of implementation of the element using the definition of the 6 levels below the definition in the yellow document

A1. Project team material status database
The project team material status database should consider the following:
- Identify which software system will be used.
- If the database will be accessed by different project participants (e.g. owner, designer, and subcontractors), will it be compatible with existing software systems among each participant.

Level 0	Project team material status database is not applicable
Level 1	No formal paper based system is used to track material status.
Level 2	There is a formal paper based system to track material status.
Level 3	A proprietary internal procurement software tool is used but it is not integrated or used by other contractors.
Level 4	An available software application is used but it is only integrated internally with your company's project control systems.
Level 5	An available software application is used by all contractors that is integrated with your supply chain and other project control systems.

5. Select the appropriate definition level. (E.g.: there is a formal paper based system to track material status. **Definition Level = 2**). **Check (√) the corresponding box in the white sheet.**

MATERIALS MANAGEMENT

Section						
Element	0	1	2	3	4	5
A. Materials Management Systems						
1. Project team material status database *(p4)*			√			
2. On-site material tracking technology *(p4)*						

6. Move to the next element

PROJECT SCORE SHEET

Please only check (√) one box per element. Please do not leave any elements blank.

The page number next to each element refers to the Productivity Practices Index Elements Description document in yellow (which contains the elements definitions).

MATERIALS MANAGEMENT

Section						
Element	0	1	2	3	4	5
A. Materials Management Systems						
1. Project team material status database *(p4)*						
2. On-site material tracking technology *(p4)*						
3. Material delivery schedule *(p5)*						
4. Procurement plan for materials and equipment *(p5)*						
B. Receipt and Inspection of Materials						
1. Material inspection process *(p6)*						
2. Material inspection team *(p6)*						
3. Post receipt preservation and maintenance *(p7)*						

EQUIPMENT LOGISTICS

Section						
Element	0	1	2	3	4	5
A. Site Tool Management						
1. Site tool and consumables management strategy *(p8)*						
2. Tool tracking systems *(p8)*						
3. On-Site tool maintenance *(p9)*						
4. Control system for tool delays *(p9)*						
B. Machinery Availability						
1. Construction machinery productivity analysis *(p10)*						
2. Equipment maintenance *(p10)*						

Please only check (√) one box per element. Please do not leave any elements blank.

The page number next to each element refers to the Productivity Practices Index Elements Description document in yellow (which contains the elements definitions).

CRAFT INFORMATION SYSTEMS

Section						
Element	0	1	2	3	4	5
A. Short Interval Planning						
1. Short Interval Planning *(p11)*						
B. Work Face Planning						
1. Well defined scope of work *(p11)*						
2. Utilization of software to assist in generating work packages *(p12)*						
3. Project model requirements *(p13)*						
4. Dedicated Planner *(p13)*						
5. Identify required permitting *(p14)*						
6. Engineering Work Packages (EWP) *(p14)*						
7. Construction Work Packages (CWP) *(p15)*						
8. Field Installation Work Packages (FIWP) *(p16)*						
C. Constructability Review						
1. Design readiness for construction *(p16)*						
2. PPMOF evaluation *(p17)*						

HUMAN RESOURCE MANAGEMENT

Section						
Element	0	1	2	3	4	5
A. Training and Development						
1. Trades technical training *(p18)*						
2. Career development *(p18)*						
B. Behavior						
1. Nonfinancial Incentive Programs *(p18)*						
2. Financial Incentive Programs *(p19)*						
3. Social Activities *(p19)*						
C. Organizational Structure						
1. Maintain Stability of Organization Structure *(p20)*						
2. Clear Delegation of Responsibility *(p20)*						
D. Employment						
1. Retention Plan For Experienced Personnel *(p20)*						
2. Exit Interview *(p21)*						

Please only check (√) one box per element. Please do not leave any elements blank.

The page number next to each element refers to the Productivity Practices Index Elements Description document in yellow (which contains the elements definitions).

CONSTRUCTION METHODS

Section						
Element	0	1	2	3	4	5
A. Sequence and Scheduling of Work						
1. Integrated Schedule *(p22)*						
2. Work Schedule Strategies *(p22)*						
3. Schedule Execution and Management *(p23)*						
B. Start-Up, Commission, and Turnover Plan						
1. Planning for Start-Up *(p24)*						
2. Testing Procedures *(p24)*						
3. System Turnover Procedure *(p25)*						
C. New Product Investigation						
1. New equipment investigation *(p25)*						
2. New information system investigation *(p26)*						
3. New materials technologies Investigation *(p26)*						
D. Site Layout Plan						
1. Dynamic site layout plan *(p27)*						
2. Site security plan *(p28)*						
3. Equipment positioning strategy *(p28)*						

ENVIRONMENT, SAFETY, AND HEALTH

Section						
Element	**0**	**1**	**2**	**3**	**4**	**5**
A. Job Safety						
1. Zero Accident Techniques *(p30)*						
2. Task Safety Analysis *(p30)*						
3. Identification of Potential Hazards *(p31)*						
4. Housekeeping *(p31)*						
5. System test hazards planning *(p31)*						
B. Substance Abuse Programs						
1. Substance Abuse Programs *(p32)*						
C. Safety Training and Orientation						
1. OSHA Compliance Training *(p33)*						
2. Toolbox safety meetings *(p33)*						

How long did it take you (or your team) to fill out the Project Rating Information forms?

Please specify in total work-hours (for example, a team of three working for four hours equals 12 total work-hours).

Project Rating Information: ___________total work-hours

Thank you very much for your participation in this survey!

Please return this form to:

Jiukun Dai, PhD
Construction Industry Institute
3925 W. Braker Lane (R4500)
Austin, TX 78759-5316

Productivity Practices Index

References

Adrian, J. J. and Boyer, L. T. (1976). "Modeling method-productivity."Journal of the Construction Division, ASCE, Vol. 102-1, pp. 157-168.

Allmon, E., Haas, C., Borcherding, J. and Goodram, P. (2000) "US construction labour productivity trends", 1970– 1998. Journal of Construction Engineering and Management, 126(2), 97–104.

Caldas, C.H., Grau, D., and Haas, C.T. (2006). "Using Global Positioning System to Improve Materials-Locating Processes on Industrial Projects." Journal of Construction Engineering and Management, 132 (7), 741-749.

Borcherding, J. D., and Garner, D. F. (1981). "Workforce motivation and productivity on large jobs." Journal of the Construction Division, ASCE, 107(3), 443-453.

Borcherding, J. D., Sebastian, S. J., and Samelson, N. M. (1980). "Improving motivation and productivity on large projects." J. Constr. Div., ASCE, 106(l), 73-89.

Business Roundtable (BRT) (1982a). Measuring Productivity in Construction. Report No. A-1, New York.

Caldas, C. H., Gibson Jr., G. E., Weerasooriya, R., and Yohe, A. M. (2009) "Identification of Effective Management Practices and Technologies for Lessons Learned Programs in the Construction Industry." ASCE Journal of Construction Engineering and Management, 135(6), 531-539.

Cho, C.H.,(2000). "Development of the Project Definition Rating Index (PDRI) for Building Projects." Ph.D. Thesis, The University of Texas at Austin, Austin, Texas.

Construction Industry Institute (CII) (1986). Costs and Benefits of Materials Management Systems . Research Summary 7-1, Austin, TX.

Construction Industry Institute (CII) (1990a). Productivity Measurement: An Introduction. Research Summary 2-3, Austin, TX.

Construction Industry Institute (CII) (1996). Design for Safety. Research Summary 101-1, Austin, TX.

Construction Industry Institute (CII) (1999). Employee-Based Project Incentives. Research Summary 140-1, Austin, TX.

Construction Industry Institute (CII) (2001). Craft Labor Productivity . Research Summary 143-1, Austin, TX.

Construction Industry Institute (CII) (2001). Engineering Productivity Measurement. Research Summary 156-1, Austin, TX.

Construction Industry Institute (CII) (2003). Safety Plus: Making Zero Accidents A Reality. Research Summary 160-1, Austin, TX.

Construction Industry Institute (CII) (2006). Work Force View of Construction Productivity. Research Summary 215-1, Austin, TX.

Construction Industry Institute (CII) (2007). Construction Industry Craft Training in the United States and Canada . Research Summary 231-1, Austin, TX.

Construction Industry Institute (CII) (2008). Leveraging Technology to Improve Construction Productivity . Research Summary 240-1, Austin, TX.

Construction Industry Institute (CII) (2009). Information Integration to Improve Capital Project Performance. Research Summary 258-1, Austin, TX.

Construction Industry Institute (CII) (2009). Construction Productivity Program – Phase I. Research Summary 252-1, Austin, TX.

Construction Industry Institue (CII) (2010). Construction Productivity Program – Phase II. Research Summary 252-1a, Austin, TX.

Construction Owner Association of Alberta (COAA) (2008). " COAA Workface Planning Rules". Web Dec. 2010. < http://www.workfaceplan.com/archive.htm>

Cox, R.F., Issa, R.R.A., Ahrens, D. (2003), "Management's perception of key performance indicators for construction", Journal of Construction Engineering and Management, Vol. 129 No.2, pp.142-51.

Dai, J., Goodrum, P.M. and Maloney, W.F., (March 2009). "Construction Craft Workers' Perceptions of the Factors Affecting Their Productivity" Journal of construction engineering and Management, ASCE, 217-226

Doloi, H.,(August 2008) Application of AHP in improving construction productivity from a management perspective, Construction Management and Economics) 26, 841–854

Ergen, E., Akinci, B. (2006) "Locating Building Components Within A Facility Using Radio Frequency Identification Technology." Joint International Conference on

Computing and Decision Making in Civil and Building Engineering, ICCCBE 2006, June 14-16. 2006, Montreal, Canada

Goodrum, P. and Gangwar, M., (July 2004) "The Effectiveness of Safety Incentives in Construction", ASSE Journal of Professional Safety.

Goodrum, P. and Dai, J., (2005) "Occupational Injuries, Illnesses, and Fatalities: Differences Among Hispanic and Non-Hispanic Construction Workers", ASCE Journal of Construction Engineering and Management, 131(9), 1021-1028.

Grau Torrent, D. (2008). "Development of a Methodology for Automating the Localization and Identification of Engineered Components and Assessment of its Impact on Construction Craft Productivity." Ph.D. Thesis, The University of Texas at Austin, Austin, Texas.

Grau, D., and Caldas, C.H., (2009). "Methodology for Automating the Identification and Localization of Construction Components on Industrial Projects." Journal of Computing in Civil Engineering, 23(1), 3-13.

Harrington, H. J., (1987). "The Improvement Process: How America's leading companies improve quality". New York, McGraw Hill.

Hee-sung Park, H. (2006) " Conceptual Framework of Construction Productivity Estimation", KSCE Journal of Civil Engineering Vol. 10, No. 5 / September 2006

Hinze, Jimmie, "Improving Safety Performance on Large Construction Sites" CIB W-99 International Conference in San Paulo, Brazil, Construction Project Management Systems: The Challenge of Integration, San Paulo, Brazil, March 25-28, 2003.

Hinze, J., and Parker, H. W. (1978). "Safety: productivity and job pressures." J. Constr. Div., ASCE, 104(l), 27-34.

Hinze, J., and G. Wilson. 2000. Moving toward a zero injury objective. Journal of Construction Engineering and Management, 126(5):399-402.

Klanac, G.P. and Nelson, E.L. (2004) Trends in construction lost productivity claims. Journal of Professional Issues in Engineering Education and Practice, 130(3), 226–36.

Lam, S.Y.W. and Tang, C.H.W. (2003) Motivation of survey employees in construction projects. Journal of Geospatial Engineering, 5(1), 61–6.

Le, T. (2009). “Improving Right-of-Way Acquisition in Highway Projects through Scope Definition and Management of Inherent Factors.” Ph.D. Thesis, The University of Texas at Austin, Austin, Texas.

Liberda, M., Ruwanpura, J., and Jergeas, G. _2003_. “Construction productivity improvement: A study of human, management and external issues.” Proc., Construction Research Congress _CD-ROM_, ASCE, Reston, Va.

Liou, F. and Borcherding, J. D. (1986). “Work sampling can predict unit rate productivity.” Journal of Construction Engineering and Management, 112, 90-103.

Navarro, L. (2009). “An analysis of global procurement and materials management practices in the construction industry.” MS Thesis, The University of Texas at Austin, Austin, Texas.

O’Connor, J.T. (1997). “Planning for Startup”, Implementation Resource 121-2, Construction Industry Institute, Austin, TX, Oct. 1997 (150 pp.)

O’Connor, J.T., and Goucha, H. Y. (1995). “Improving Industrial Piping through Vendor Data and Packaged Units Processes.” Construction Industry Institute, Research Report 47-11.

Oglesby, C.H., Parker, H.W. and Howell, G.A. (2002) Productivity Improvement in Construction, McGraw-Hill, New York.

Parham, D. and Zheng, S. (2006) Aggregate and industry productivity estimates for Australia. Australian Economic Review, 39(2), 216–226.

Park, H. S. (2002). Development of Construction Productivity Metrics System (CPMS). Dissertation, Department of Civil Engineering, University of Texas, Austin, TX.

Park, H. S., Thomas, S. R., and Tucker, R. L. (2005). “Benchmarking of construction productivity.” Journal of Construction Engineering and Management, ASCE, Vol. 131-7, pp. 772-778.

Peltier, E. J. (1978). “Productivity in the construction industry management processes.” Journal of Professional Activities, ASCE, Vol 104-1, pp. 53-56.

Pilcher, R. (1997) Principles of construction management. McGraw-Hill, London.

Rojas, E. and Aramvareekul, P. (April 2003). “Labor Productivity Drivers and Opportunities in the U.S. Construction Industry.” Journal of Management in Engineering, ASCE, 19 (2), 78-82.

Thomas, H. R. and Napolitan, C. L. (1994). "The effects of changes on labor productivity: Why and how much." Source Document 99, Construction Industry Institute (CII), The University of Texas at Austin.

Thomas, H.R., Riley, D.R., and Messner, J.I. (2005). "Fundamental Principles of Site Materials Management." Journal of Construction Engineering and Management, 131(7), 808-815.

Thomas, H. R., Riley, D. R., and Sanvido, V. E. (1999). "Loss of labor productivity due to delivery methods and weather." Journal of Construction Engineering and Management, ASCE, Vol. 125-1: pp.39-46.

Thomas, H. R. and Sanvido, V. E. (2000). "Role of the fabricator in labor productivity." Journal of Construction Engineering and Management, ASCE, Vol. 126-5, pp. 358-365.

Thomas, H. R., Sanvido, V. E., and Sanders, S. R. (1989). "Impact of material management on productivity-A case study." Journal of Construction Engineering and Management, ASCE, Vol. 115-3, pp. 370-384.

Thomas, H. R. and Yiakoumis, I. (1987). "Factor model of construction productivity." Journal of Construction Engineering and Management, ASCE, Vol. 113-4, pp. 623-638.

Thomas, H. R. and Sakarcan, A. S. (1994), "Forecasting Labor Productivity Using Factor Model", Journal of Construction Engineering and Management, Vol. 120, No.1, pp.228-239.

Triplett, J., and Bosworth, B. (2004). "Productivity in the U.S. Services Sector: New Sources of Economic Growth." Brookings Institution Press, Washington, D.C..

Tucker, L. R. (1986). "Management of construction productivity." Journal of Management in Engineering, ASCE, Vol. 2-3, pp. 148- 156.

Weber, S. F. and Lippoatt, B. C. (1983). "Productivity measurement for the construction industry." Technical Note 1172, National Bureau of Standards (NBS), Washington, DC.

Zhao Ying, (2004) " Significant factors affecting construction productivity". Master thesis. National University of Singapore.

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